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A packet radio logistic network for a Marine amphibious landing force.

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A PACKET RADIO LOGISTIC NETWORK FOR
A MARINE AMPHIBIOUS LANDING FORCE

by

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A Packet Radio Logistic Network
for
A Marine Amphibious Landing Force

by

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ABSTRACT

The purpose of this thesis is to describe a deficiency in current Marine Corps logistic communication, investigate various technical solutions and select an appropriate design to eliminate this deficiency. The intention is not to answer all of the questions related to the topic, but to demonstrate that technology has advanced to a point where it is possible to provide an inexpensive solution to this particularly difficult problem. Although further research will be required, this thesis will indicate that the technology is not only conceivable, practical and efficient, but well within reach. The thrust is to marry a relatively new, but proven, technology with a real world problem and to direct further attention to the effort, so that a practical solution can become a reality. As a result, The Marine Corps could possess a faster, more reliable logistic communication system while deployed and thus have an added advantage during a conflict.

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I. INTRODUCTION

A. PURPOSE

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B. CHAPTER DESCRIPTION

The following chapter of this thesis will be a mission element need statement. The purpose will be to describe a deficiency in Marine Corps logistic communication and processing at the local level. "Local level" is defined as that communication and processing of logistic requests from the actual customer (maintenance clerk, company commander) through the logistics chain of command to the force service support group. The emphasis will be placed on deployed operations but will not rule out applications in garrison. The priority of this deficiency will be discussed and a preliminary cost estimate provided. No solutions, however, will be addressed at this point. The intention will be purely to demonstrate that there is a deficiency in Marine Corps logistic operations.

The third chapter will highlight current technological advancements in the field of packet radio computer networks. The fact that packet radio computer networks are not at the leading edge of technology, but are a proven technology, will also be demonstrated in this chapter. Problems, advantages and options will be elaborated on in a generic sense i.e., not necessarily related to the problem identified in the mission elements needs statement.

The fourth chapter titled "design" will develop a prototype design and will discuss system specifications. These specification will be as precise as possible based on currently available statistics and experience. Many aspects of the network will be examined and specifications will be described for the hardware. This will be accomplished by breaking the network design down into sections. First, we will study the required attached equipment at a typical repeater node, then we will examine the network or the method of communication between nodes, and finally we will examine the control node or station.

The last chapter will point out each of the positive and negative aspects of the proposed system and recommend a direction for further research. A summary proposing certain future actions and considerations will conclude this thesis.

Appendix A is a list or acronyms used through the thesis. Each acronym is explained to clarify the use of terms unique to the military.

C. DESIGN PRINCIPLES

A number of principles will be applied and emphasised throughout this thesis. These principles may seem elementary but a reemphasis of the basics is important when dealing with critical systems, especially when human lives are at stake. As such, they are described in the next four paragraphs to clarify basic design considerations and constraints.

1. Simplicity

The first design principle is simplicity. This may be an overworked concept, but it is evident from the catastrophic results of many computer systems that the designers have often times dismissed simplicity as an important constraint. The design of this computer network is only as complex as the problem dictates. The basic concept is: first, identify the problem; second, investigate the kind of tools that can be used to solve the problem; then finally, develop a design. As a result, design functions will translate directly into solutions to the previously identified problem without unneeded complexity.

2. Customer First

The second principle is the emphasis on customer needs.[1] Throughout this thesis, the basic customer needs will be delineated and solutions will be developed in strict relation to those needs. The basic needs of the customer (the maintenance clerk

[1]The customer is that person that initiates a logistic request.

etc.) will be emphasized as opposed to the needs of the system or those of the source of supply. The source of supply and the system will be developed to serve the customer, instead of the other way around. If functions do not serve a real customer need, an alternative will be sought that will fulfill these requirements. If an acceptable alternative cannot be found, then no change to current operating procedures should be made. Although, again, this may seem overly simplistic because of the complexity of computer system development, it is possible to develop a system that upon completion has lost sight of its original goal.

3. Flexibility

The third principle is flexibility. It must be kept in mind that a computer system is more than just a machine. By definition, people are an integral component of any computer system [Ref. 1: p. 22]. As a result, with emphasis on the word 'system', as much flexibility as possible will be built into the design. This is to insure that when a request is made and something is not quite in the right format, the request will not be returned but will be diverted to a manual review process and or an error correction process. There will be rules and procedures, of course, but one of the goals of the system is to be able to accommodate all but the most grievous of errors. This is especially necessary in combat situations where bureaucratic procedure is not a suitable reason for delay.

4. Reliability

The fourth concept is reliability. In military operations reliability is one of the highest priorities. The proposed design will consider reliability over most other considerations. As a result, back-up procedures will be implemented. As much effort as possible will be given to providing the system user with alternative means of communicating and processing. In addition, the programs should contain means with which to identify failure and any avenue around failure, so that the system will be as reliable as possible. In view of these safeguards, the system should operate under any weather conditions, in urban areas and or in the jungle, in mountains or on flat lands, in combat or in garrison. The task of adding and deleting members to and from the network should also be accomplished with ease. Routing should be flexible enough to allow for redundant means of communication. Thus, we will strive to provide a robust network which will be able to operate even in the most harsh environments.

II. MISSION ELEMENT NEED STATEMENT

A. BACKGROUND

In order to obtain a full appreciation of the problem of communicating logistic demands during a Marine amphibious landing, a basic understanding of the landing force structure is necessary. A brief description of this structure will be outlined in the following paragraphs.

A Marine amphibious force is a mobile and flexible unit that must be able to adapt to changing environments. For example, while aboard ship the landing force reports to the Navy. Once ashore, however, it reports via Army channels. The Marines must, therefore, rapidly adapt themselves to both organizations. This usually causes a great deal of difficulty when planning and coordinating support functions. This problem is complicated further by the fact that Marines possess both air and ground forces. The Marine air element must coordinate with the Navy aboard ship, but must deal with the Air Force missions and capabilities while ashore.

The Marine landing force itself is divided into four parts: a headquarters element, an air element, a ground element and a support element. Depending on the size, this configuration can be formed into three types of landing forces: a Marine Amphibious Force (MAF), which is the largest force and is formed around a division; a Marine Amphibious Brigade (MAB), which is built around a regiment; and a Marine Amphibious Unit (MAU), which is the smallest configuration and is formed around a battalion.

The headquarters element consists of the landing force commander and his staff, along with a small group of communicators.

The air element consists of helicopter support and for larger operations, fixed wing aircraft. The air defense and air control missions are also assigned to the air element.

The ground element is commanded by the infantry unit commander. Under the infantry unit commander are a number of support sections i.e., tanks, recon, amtracks, communicators, combat engineers, etc. Artillery is included here, but artillery's mission is also to support the entire landing force, not just the ground units.

The support element provides most of the logistic support to the landing force. Supply, maintenance, engineering, medical, dental, motor transport and landing support fall into this category.

Marine amphibious logistic support is for the most part centralized at the support element. Thus, a unit requiring logistic support must communicate its requests to the support element. During deployment these requests are normally processed manually.

The major problem dealt with in this thesis is how logistic communication and processing is accomplished. It will also be shown that both the logistic communication and the local processing aspects of this procedure are very time consuming. To demonstrate this point, supply demands, which are the most numerous and time intensive, will be examined in detail. The ideas generated from this examination could, however, be easily applied to other types of logistic transactions i.e., maintenance, motor transport, engineering, etc. The term "local level" will be used to describe this form of communication and processing procedures.

B. MISSION AREA

The force service support groups (FSSG) of the Marine corps provide logistic support within their capabilities to the MAF's. The supply battalion within the FSSG maintains the responsibility for providing responsive supply support for most classes of supply material required by MAF units. Class III (petroleum products) supply support is provided by the FSSG engineer battalion while unique aviation items are provided by the wing supply staff.[2] Implied in these mission statements is the requirement to establish procedures for processing logistics requests initiated by MAF customers. The faster these requests are processed, starting with the customer identification of need, the more responsive the supply support. Thus, to insure responsive supply support, it is the responsibility of these support activities to establish systems that will process requests in the most rapid manner possible, whether in garrison or while deployed.

[2]This is verified by the mission statement of the Marine Corps 3rd Force Service Support Group, Okinawa, Japan.

C. MISSION ELEMENT NEEDS

1. Problem Identification

Over the years, the military has succeeded in developing extremely capable logistic communications systems over long distances. Military personnel can send a supply document from Okinawa to any DOD source of supply via AUTODIN (the military data communication system). This can be accomplished by filling out a 1348 Navy form or by keypunching the appropriate information onto a card or magtape which is dropped off at the nearest communication center. The communication center processes this information as it would a naval message, in accordance with its priority, and once inserted into AUTODIN the message is delivered to the source of supply in minutes, if not seconds. At most sources of supply, these requests are processed immediately (or within a few hours) against on hand stocks. Status is then instantly sent back to the originating communication center.

The question may then be asked by those who have worked with supply documents and status in the Fleet Marine Force: "If we have such a fast communication system, why does it take weeks for status to be posted to supply or maintenance reports?" The answer to this question is that the local processing by the communications center, and the local systems, slows the process considerably. The difference between the ability of the communications center to transmit and receive messages from its electronic system and the ability of users to deliver and receive information from the communication center is significant.

The point to be made here is that communicating logistic data across the world from Okinawa, to Albany, Georgia, is not the problem. The actual problem is processing and communicating logistic information from Motor Transport Section, HQ Company 4th Marines at Camp Shwab, Okinawa to the 3rd FSSG communication center at Camp Kinser, Okinawa. To make matters worse, how does the logistic clerk communicate logistic demands from Unchon, Korea, or Dingralin Bay in the Phillipines, to his first source of supply and then to the 3rd FSSG communication center in Okinawa? The problem is not the actual transmission speed, which takes only seconds, but in getting the message to the communication center i.e., local processing and communicating.

2. Problem Examination

Since this thesis addresses the logistic communication of a deployed unit, we will examine the process from this point of view. These procedures are similar to those used in garrison, but a look at deployed operations demonstrates the problem more clearly. While deployed, a logistic request is delivered by the customer to the first source of supply (the issue point). The issue point processes the request and, if necessary, communicates it back to a garrison source of supply. If the demand cannot be filled at the garrison source, it is delivered to the supporting communication center for transmission to a DOD source of supply. So, why is there such a local delay problem? There are essentially three factors to consider:

One: The link between the customer and the issue point is a difficult and slow communication procedure.

Two: Processing at the issue point is bureaucratic and slow.

Three: The numerous steps involved in processing demands at the local level decreases response time.

a. The Link

Problem # 1 is the keystone of this thesis. The ability of the customer to communicate a request while deployed, to the issue point, is often an overwhelming problem, and a frustrating one in garrison.

(1) *Communication.* Consider the simplest case: a Marine Amphibious Unit landing. Where is the source of supply? Initially, it is kept aboard ship. When the issue point is aboard ship, how does a shore unit deliver a request to the issue point? If any support is provided at all, the request must be voice communicated to the tactical logistic operation center (TLOC).[3] This process consumes valuable communication capabilities, using voice channels that are critical for command and control. The process is troublesome, so much so, that it is usually simply not attempted. At this stage of the amphibious landing there is limited, if any, ability to communicate logistic data.

Once ashore, the issue point may begin to support the forces more efficiently. But what about the unit 20 or 30 kilometers inland? What type of support can it expect in a hostile environment? The only practical means of communicating

[3]The TLOC is the section in the support element that accepts all customer requests and directs support action. It can be though of as the support element's operation center.

supply requirements is via courier. Will the commander dedicate a man and a vehicle to go on a supply run back to the beach? This may be considered, but it will certainly not be accomplished in a responsive manner. Within the existing system, we talk in terms of days while today's modern communication and processing technologies can accomplish such tasks in milliseconds.

(2) *Transportation.* A second difficulty, associated with the logistic link between the customer and the support element, is transportation. First, let us assume that the support element is now ashore. In such cases, the primary means of communication between the customer and the issue point is by courier. Unless the customer is within walking distance, the courier will require motor transportation. This is a time consuming activity that requires detailed planning and often must be shared with other missions. Waiting for transportation further delays the communication of logistic requests.

On the other hand, let us assume that the support activity is still aboard ship when a request is received and that the supply block is embarked, enabling a warehousemen to pull the item off the shelf (often not the case). The next question is, how will the item be delivered ashore? This new transportation request must compete with other critical demands for the extremely limited transportation assets available between ship and shore during an amphibious landing. This is another form of transportation delay.

(3) *Procedures.* A third factor associated with the logistic link concerns the procedures used by customers. A logistic request is initiated by a unit in one of the landing force elements, for example. This request, in some cases, must flow up the unit's chain of command to the support activity. In other words, a request made by a company commander must be approved by the company's battalion, regiment and division before it is provided to the support activity. These steps are necessary in order to maintain control over demands and to keep higher echelons of command informed. It also causes considerable delays and bureaucratic frustrations. For a unit well inland, the effort and dedication of assets necessary for proper logistic support is not perceived to be worthwhile in the short run.

In time, for the following reasons the difficulty of communicating logistic transactions to the issue point, the limited transportation available for logistics support, and the procedures that require all echelons of command to approve certain requests, logistics support falls far behind the actual need. This time lag is often a matter of days, if not weeks. The logistic support link is a very complex process requiring the support of other functions such as transportation and communications. For a MAB or MAF the complexity and delay become even more significant. Under these situations units are even more spread out, making it more difficult to communicate demands to issue points. Add this complexity to a live combat environment and the potential for improvement is clearly evident.

b. Local Processing

The second major problem at the local level is the fact that processing at the issue point is extremely slow. A description of several of these processes will be discussed in the following paragraphs.

Class IX (repair part) requests are normally filled out on 80 card column manual forms commonly referred to as 4 cards. The customer is required to do all the required research to identify the proper stock number, the unit of issue, etc. These 4 cards are then sent by courier to the issue point. If the supply platoon is not busy, however, the customer may receive an over-the-counter issue. Most of the time, the customer can expect to submit the 4 cards on one day, and pick up the parts on the next day. One whole day is wasted at this point alone. In order to understand why over-the-counter issue service is not provided on all occasions, it is necessary to take a closer look at the issuing process.

There is a tendency among supply officers to throughly research all requests prior to a stock check. Primarily, this is done to insure that incorrect stock numbers are not counted as stock denials, which could adversly affect the fill rate. The research, which validates each stock number, takes up a lot of time and is one reason for processing delays. Another reason is the fact that customers normally deliver a large number of requests at one time. This happens mainly because distance, or vehicle availability, prohibit frequent trips to Supply. As a result, one customer may tie up Supply for an hour or more. This is a typical example of a queue with a high service time variance in which the queue length increases progressively. In view of these problems, customers simply find it easier to leave the paper work off at Supply and pick it up later.

Once an item is issued, the processing of demands at the issue point is also a time consuming task. The proper transactions are processed on an IBM Series 1 computer. Once enough transactions have been accumulated, a batch update formats the transactions on a diskette for later transmission to the next source of supply. This could, and usually does, produce days of delay. If experienced people are running the update, and if the update goes smoothly, a one-day delay may occur. Time has proven though that this equipment is rarely operated by experienced personnel. As a result, two or three days are often lost in trying to get the update to run properly.

c. Many Steps

The fact that there are numerous steps involved in processing a request at the local level is the third major problem. In providing supply support to deployed units at the 3rd FSSG the supply support personnel calculated in 1983 that there were actually 47 steps involved in providing one small repair part from Okinawa to a deployed unit. These steps include action taken by communicators, maintenance clerks, supply clerks, warehousemen, forklift drivers, transport personnel, Air Force air embarkation personnel and packaging personnel.

D. EXISTING SOLUTIONS

1. The Procedural Approach

To lessen the impact of these problems, Marines have developed basically two procedural approaches. The first of which is to divide up the support element into smaller sections, in order to provide support closer to the customer. As such, the ground and air elements may receive their own support detachment (DET). To illustrate this point perhaps each regiment, or even each battalion, could receive their own DET. This would provide support closer to the customer, in a decentralized manner, while lessening the demand for transportation and communication. But, because the battalion and regiment must maintain mobility, only a few items could be stocked in these DET's. This would trigger a redistribution problem as a result of stocking only a limited number of items. A problem of this nature is one that is created when a customer sends a request to the first source of supply. That source of supply does not stock the needed item, but, possibly one of the other issue points does. The problem is: How does the customer know which other issue point may stock the part? The problem of positioning support too close to the customer, therefore, is that a greater communication problem developes due to the redistribution of demands.

A second alternative solution to the logistic support problem from a procedural perspective is to avoid the chain of command. When a unit has a logistic need, it merely sends the requests directly to the source. The obvious disadvantage here is that both command and control suffer. Some requests need to be filtered through the chain of command to insure their validity and/or to insure a proper allocation of resources to all subordinates. This does not indicate that some logistic traffic could not flow directly to the support element. Simple supply requests for repair parts normally do go directly to the supply issue point, which does save time. In such cases, there is no reason for higher commands to review these demands, since the mechanic is the only one who really knows whether or not the request is valid.

2. The Technical Approach

a. DMGS

Recently, there have been a number of systems developed for deployed units to perform the same functions as a remote job entry system (RJE) does but which use communication media that allow for mobility. RJE's are tied to fixed telephone lines, so they cannot be moved easily. Systems like the deployed message generating system (DMGS), and others, send logistics transactions from deployed sites to the FSSG communications center via the same media used to transmit naval message traffic (HF, satellite). The transactions are held at the base data processing facility, until the next SASSY[4] cycle, at which time they are automatically processed.

In the past, we have encountered numerous problems with systems like DMGS. When trying to interface with the varying support agencies we found that they were inexperienced in processing transactional traffic. This inexperience led to a great deal of confusion, which resulted in costly delays and loss of important data.

b. DFASC

The deployed force automated service center (DFASC) was part of another attempt to reduce the impact of local processing delay. The initial idea was to accomplish all local processing within close proximity to the customer. Instead of sending logistic traffic back to a garrison computer for processing, for instance, the processing was accomplished at the deployed site by a mobile IBM 4341 mainframe computer. The DFASC has allowed the SMU[5] to deploy and operate in the field providing the same automation services that the SMU now provides in garrison. The output from this process could also then be directly entered into AUTODIN. This concept has provided a higher degree of information management in the deployed environment.

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[4]SASSY is the Marine Corps automated supply system.

[5]The SMU is the SASSY management unit which serves as the source of supply for issue points and accepts input and distributes SASSY output to customers.

E. PLANNED SYSTEMS

None of the above systems address the customer-to-issue-point link. However, there are a few systems under development that could be expanded to include this concept. The Maritime Prepositioned Support (MPS) Decision Support System, or MDSS, attempts to provide the landing force commander with asset visibility.[6] The Combat Service Support Information System, or CSSIN, attempts to coordinate the many blocks of items sent by the war reserve system (WRS), and others, during a real conflict [Ref. 2]. Once organized and centralized, a particular item may be easily located. These systems attack specific problems and demonstrate the need for asset visibility on the battlefield. To make these systems more potent, however, the associated files must be updated rapidly by customers. The poor link that exists between the customer who consumes assets, and MDSS or CSSIN, must be addressed as an important constraint before a solution can be developed. If this link can be tightened, it will enhance these two new support systems remarkably. Not only will the landing force commander gain asset visibility, he will be able to achieve real-time visibility.

F. IMPACT

The priority of the logistic communication problem is difficult to quantify. Logistics communication in the early stages of an operation, when the support element is still aboard ship, is usually poor. Nevertheless, there are those who would argue that logistics, in the early stages, are not important. This is assuming that equipment will operate the way it is supposed to, once it rolls ashore. However, it is always better to have some sort of equipment back-up to rely on in complex operations such as an amphibious landing. Even after the support element is ashore, as previously mentioned, logistics requests are usually not made because of the time element involved. In view of this, whenever a major weapons system fails the needed parts are often obtained by cannibalizing like items. These tactics have short term advantages, but in a lengthly campaign could, and will, prove disastrous.

Because MAF units cannot easily communicate logistics data, they are forced to operate without needed support. As we become more dependent on machines, we must learn to provide for more rapid means to support this equipment. Without the proper support, our equipment status will quickly decline.

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[6]Information obtained from interview with Lt Col Donald E Mears HQMC I+L 28 Aug 1986.

In order to get some feel for the possible impact of poor logistic support while deployed in a prolonged operation, consider a garrison MAF. Most MAF's maintain an equipment readiness rate of close to 90%. In peacetime, a garrison MAF processes 30-50 thousand supply demands in a month.[7] Consider that there would be a much higher failure rate while deployed, if for no other reason, than because the equipment is run longer. Would we be able to process the 30-50 thousands of demands a typical MAF now processes monthly, in the first 30 days? Even on large exercises, we are only able to process 100 to 150 transactions a day which is only 1/10 of the garrison volume. Could we really hope to maintain high equipment readiness using the current logistic communication system previously outlined? It is obvious that the equipment readiness rate will depend greatly on the ease of being able to request support. Streamlining and facilitating these logistics procedures will provide a clear advantage.

G. COST ESTIMATIONS

In the private sector Packet Radio has been used to solve similar logistic communication problems.[8] In 1980 the projected cost of a packet radio, in five years time was, $5,000 [Ref. 3: p. 1]. Fielding down to the company, battery and/or squadron level would require approximately 200 radios per MAF. Table 1 show estimated costs. Of course these are extreme cost estimates not based on in-depth research but they do provide a tentative cost approximation.

H. SUMMARY

The preceding mission elements needs statement has attempted to demonstrate the fact that requesting logistic support in garrison, and especially while deployed, is a complex coordination problem which may take days to complete. The following chapters will explore the possibilities of using packet radios to improve logistic responsiveness within deployed forces.

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[7] Supply demand rate obtained from official Marine Corps records for the months Oct to July 86.

[8] Phone conversation with Federal Express Public Relations Department on 29 Dec 86 indicated they use packet radios to trace packages. Each truck is equiped with a packet radio so a delivery confirmation can be sent to a central computer immediately.

TABLE 1

PACKET RADIO NETWORK COSTS ESTIMATES

200 X 3 (MAF'S) = 600 X $5,000 =	$ 3 000 000
Cost of Spares =	$ 3 000 000
Software Costs Using COCOMO =	$ 054 000
Testing and Development =	$ 1 000 000
Total Cost =	$ 7 054 000
Deployment Cost =	$ 200 000 per year

III. PACKET RADIO TECHNOLOGY

A. INTRODUCTION

Packet radio was created by merging packet switching with standard radio technology. This technology takes advantage of the ability to communicate between computers using radio wave propagation, instead of the traditional hardwire media. In other words, if someone has a packet radio they will be able to communicate with a distant computer by linking to that computer via radio waves, instead of the standard telephone lines.

Packet radio borrows heavily from an earlier technology known as packet switching. Packet switching, which was developed primarily for the DOD ARPANET in the late 60's, divides messages up into small standard length segments called packets and sends these packets individually through the network [Ref. 4: p. 32].

Packet radio similarly sends messages in short bursts of radio wave propagation, or packets. The ALOHANET, one of the original packet radio networks, sends 80 characters of data in one packet in 73 milliseconds, about 1/10 of a second [Ref. 5: p. 203]. The same information sent over a voice channel by a human would take many times longer.

The advances in micro processing over the last ten years have enabled the electronic components of a packet radio to be contained in a hand held unit which includes a keyboard and display similar to a calculator. [Ref. 3: p .7]

B. ADVANTAGES

The advantages of packet radio are basically three fold: One, it provides mobile access to computer facilities. Two, it provides a rapid means to communicate data using very little radio spectrum. Three, it has a broadcast capability which allows a sender to transmit a message to multiple locations at one time The following paragraphs detail these advantages and explain why they are particularly appropriate for the logistic communications needs of a Marine landing force. [Ref. 6: p. 1470]

1. Mobility

The advantage of mobile access allows anyone with a packet radio who is within range to access computer resources. There is no need for a special modem or telephone lines. With a packet radio, whether in a car, on a street, in the mountains or the desert, easy access is quickly available.

This advantage is ideally suited for Marine landing forces that must be mobile. Hardwire, telephone-like communications are not flexible enough to adapt to the changing needs of a Marine landing force, but packet radio is linked automatically to computer capabilities. With an omnidirectional antenna no special installation, set up, or alignment is required. All the operator has to do is turn the packet radio on and start keying in data.

2. Rapid Communications

Logistic traffic sent over a voice channel does not use the total available bandwidth. Much of the time a voice channel is available there is no information sent. This is due to the natural pauses that make speech intelligible. Voice traffic is communicated at the same rate as humans input sound. Assuming a 9600 bps data rate, 8 bits per character, and 80 characters per packet, it would take 640/9600, or 1/15 of a second, to transmit a packet. How long would it take for a person to communicate 80 characters? The potential for improvement in this area is obvious. Packet radio makes good use of a short burst of data using radio propagation, thus maximizing radio spectrum use. This capability would be of primary importance to a communications officer who is trying to satisfy the many communication needs of the total landing force.

3. Broadcast

In a traditional hardwire network, one message would have to be sent to every addressee individually. Packet radio on the other hand enables the sender to broadcast a message to any number of locations at the same time. In view of this, consider the broadcast capability applied to the problem of redistribution as described in the previous chapter. Let us assume the support element is divided up into nine DET's. When a demand cannot be satisfied at one DET it could simply be sent, in one message, to all the other DET's asking for a redistribution of the needed item. If the item was available, a redistribution could be arranged immediately.

Packet radio broadcast capability can also be used to save time by sending certain types of requisitions directly to the source, while informing the chain of command at the same time. Thus, the usual procedural delay would be minimized. Although simple supply part requests could be sent in this manner, certain other types of requests might require some sort of approval message.

C. DISADVANTAGES

There are three significant problems involving packet radio: contention for the channel, security, and reliability [Ref. 6: pp. 1472-1476]. Although there are ways of avoiding these problems, the tradeoffs result in added complexity and possibly a decrease in spectrum utilization.

1. Contention

Since there is only one frequency normally available for a packet radio network, each member of the network must share this channel. If two or more members transmit packets at the same time, a collision will occur which usually destroys both packets. A protocol must be established to detect and avoid collisions. Many such protocols have been proposed that involve complicated queuing theory. Each of these protocols use an acknowledgment scheme whereby the destination sends back a message to the source indicating that it has received the packet correctly. If the source does not receive an acknowledgment, it retransmits the packet after a random wait time.

2. Security

Since packet radio is a broadcast medium, anyone within range with a packet radio and knowledge of the frequency being used would be able to listen to the network traffic. More important to military operations, if the frequency is known, all the enemy has to do is send bogus packets (one right after the other) to jam the channel. Jamming the channel in such a way will virtually shut down the network. This is obviously a critical problem to overcome when considering any useful military application. Spread spectrum techniques such as a frequency hopping or a pseudo noise spread spectrum scheme could be used to combat this security problem. While both techniques can actually increase spectrum use by sharing frequencies, they also introduce complex synchronization problems.

3. Reliability

Packet radio relies, after all, on radio propagation and is prone to all of the same disadvantages that any radio network encounters. Line of sight links are required which make it difficult to ensure network integrity. Weather conditions, time of day and unintentional noise created by such common occurances as vehicle ignitions and so forth, could adversely affect packet radio reliability.

D. OTHER CHARACTERISTICS

There are a number of ways packet radios can be employed. As with any network, the choice of a network structure that provides the optimal service is an extremely complex problem. If structured properly, however, a packet radio network can provide a number of interesting capabilities. Some of these capabilities will be described in the following paragraphs. Additionally, the discussion includes the environments which are best suited to take advantage of these capabilities.

1. Repeaters

Repeaters are used to extend the range of packet radio networks. Radio packets can literally "hop" from one repeater to another, as many times as required, to reach their destination. One interesting aspect concerning repeaters is that the packet pulses are reshaped, retimed and retransmitted. Amplification not only amplifies the message, but also the accompanying noise. Retransmission eliminates this problem by decoding the packet at each repeater and retransmitting it, so that the only noise received at the destination point is that which is picked up during the last hop.

2. Bucket Sorting

One of the most unique aspects of packet radio technology is its broadcast ability. This concept, when applied to the common search and retrieve problem, has some interesting results. A particular application, referred to as bucket sorting, is explained below.

Bucket sorting uses packet radio broadcasting to locate an item that could be recorded at any number of locations or nodes that are all within radio range of each other. When k nodes can be accessed at the same time, the search time is reduced by 1/k multiplied by the search time without broadcast ability. For simplicity of explanation, let us say there are 16 buckets and 9 packet radio nodes and 144 items in a network. Buckets are simply categories, or names, for a group of related items. All of the 9 packet radio nodes have one storage slot for each of the 16 buckets. As such, each node can store one item per bucket (all 144 items can be stored in a unique node/bucket). Now, when a particular item is needed, a station first determines which bucket the item belongs to, then broadcasts a request for that item along with its bucket name. Each receiving node identifies the bucket and looks at the item it has stored in that bucket for a match. If there is a match, the item record is located from 144 possible items after only one attempt. Of course, this case assumes there are enough nodes and buckets so that each item can be stored in a unique node/bucket.

Practically speaking, there probably would be many items in each node bucket but this would still substantially reduce the search time. [Ref. 7: p. 177]

Bucket sorting used with packet radio broadcasting is particularly suited to situations where issue points are mobile and are required to be as close to the customer as possible i.e., many small issue points or distributed warehousing.

3. **Capture**

When two packets collide it is normally assumed that both packets are lost, but in many cases the packet with the strongest received signal will capture the channel and be received without error. The strongest packet is the one that has the strongest signal at the destination and this strength will depend on signal power and distance transmitted.

A number of mathematical analyses have been conducted which attempt to take advantage of this capture phenomenon. By assigning nodes in groups of closely located terminals and restricting each member of a particular group to a particular maximum signal strength, collisions can be reduced and throughput increased. The idea is to reduce the power of transmitters so that their transmissions can be only heard by their closest neighbors. In this way, the packets would not interfere with the rest of the network. It is clear that the fewer nodes one node can hear, the lower the probability of collision. And if a weak packet is heard while a strong one is being received, then the strong one will capture the channel. The tradeoff here is that a smaller transmission range will increase the number of repeaters required to transmit from node A to node Z. The more repeaters, the more traffic, and the more possibility for collision.

The important phenomenon described herein is called spatial reuse, and was studied in 1984 by Kleinrock and Nelson [Ref. 8: p. 684]. These two researchers tried to answer the question: How small should a group of terminals be to optimize throughput by taking advantage of capture? They found that, at most, 21% of the terminals could share the channel without interference, assuming a slotted Aloha protocol. In other words, groups could be numbered so that 21% of the terminals could send a message at the same time. This translates into groups of 5 terminals for a network of 24 nodes. It was estimated that, by properly taking advantage of capture, throughput could be increased by as much as 25%. Of course, these results depended heavily on many other factors such as the mobility of the nodes and frequency of transmissions.

4. **Priority Packets**

In 1983 Shacham published an article that analyzed the effect of assigning two levels of transmission power to two groups of terminals in a packet radio network [Ref. 9: p. 253]. Using capture, the group that transmitted at the higher signal strength would have a priority over the other group of terminals. As a result, a preferred access scheme was created. This protocol provided prioritized service which led to a higher level of performance for the priority group, while the other group's performance decreased. The point here is that a priority scheme can be easily implemented in a packet radio network by simply adjusting the signal power of nodes. The difficulty is in determining which group of terminals deserves a priority status. A possible application of this concept is discussed in the following paragraph.

The loss of an acknowledgment packet is more disruptive to network performance than the loss of the initial packet. An acknowledgment loss will result in a message being unnecessarily retransmitted, possibly more than once. Most packet radio protocol analysis assumes that acknowledgements are properly received over a separate channel. It has even been suggested that one acknowledgement be sent many times, or at the beginning and end of a packet transmission slot, to insure successful reception [Ref. 10: p. 684]. But the fact is that acknowledgement traffic uses a small amount of spectrum, since only a few bytes of data are normally required. Dedicating a separate channel for acknowledgments is, therefore, wasteful. The question now is: how can we insure acknowledgments are successfully received? One option is to send acknowledgment traffic at a higher signal strength. This would, in effect, be giving higher priority to acknowledgment packets which are more critical to network performance.

5. **Spread Spectrum**

One of the most interesting inovations in packet radio protocol research has been the application of spread spectrum techniques in dealing with the problem of contention. Spread spectrum not only allows radio signals to be received more reliably but also offers special military advantages by making it difficult for the enemy to detect and jam packet radio transmissions.

There are basically two kinds of spread spectrum techniques that can be applied to packet radio networks. These techniques are known as pseudo-noise modulation (PN) and frequency hopping (FH). Each technique can be implemented individually or at the same time [Ref. 6: pp. 1473-1476]. Although conceived in the

1940's, recent technological advances have allowed these concepts to become both economical and practical for today's use at the company grade level.

a. Pseudo Noise Modulation

PN modulation is a process in which there is a basic data stream input by the user. A pseudo random bit generator produces another stream of data (1's and 0's). The data elements in this stream are referred to as chips which distinguishes them from the original data bits. For each data bit, a fixed number of chips are generated. As an example, let us say 4 chips are generated for each data bit. These 4 chips are modulo 2 added to the associated data bit, which produces another stream of data. This stream is then sent over the radio frequency at four times the actual data rate and has the effect of spreading out the radio signal over a larger bandwidth. At the receiving station the signals are demodulated and again modulo 2 added with the same random synchronous stream of chips used at the transmitter, which reproduces the original data stream. As long as the same pseudo random chip generator code is used, and each node is synchronized, the proper information will be demodulated.

PN has the effect of spreading out the signal bandwidth, so that the actual signal resembles little more than white noise to an unfriendly observer. It produces a low spectral profile which makes it difficult to know when a channel is being used. Detection, therefore, is prohibitive as long as the enemy does not know the pseudo random chip generation scheme. At the destination point the receiver can identify its code and filter out everything else as noise. Without knowing the chip code, jamming is close to impossible whether or not the frequency is known. When received, the jamming signals are spread just like all other received traffic, however, since it is not coded properly the jamming is effectively treated like noise. The result is that PN modulation is able to pick out friendly signals on the channel from all other noise, including both intentional noise and white noise.

As a result of spread spectrum PN modulation, any signal not using the correct pseudo random code is ignored. What does this have to do with packet radio contention problems? Consider the situation where each user within a radio range uses a different pseudo code to receive packets and each node has knowledge of all the other PN codes being used. When one node wants to send a packet to another, it first determines what its code is, then generates the code, modulo 2 adds it to the data, and transmits it. In this way no collisions would occur, since other packets sent at the same time would be using a different code and would be filtered out as noise. The only way a collision could occur is if both packets were sent to the same node at the same time. In a complex network, where each node could transmit to every other node, PN modulation would significantly reduce contention. In a star network where every node must transmit to one central station, PN modulation would have no effect on contention. There is also a limit to the number of codes one channel can carry. If too many nodes use the channel at the same time the heavy traffic may make it too difficult to identify the properly coded signal.

PN modulation also combats the effects of the multipath phenomenon [Ref. 6: p. 1472]. Multipath is simply the echo effect of radio propagation. When a radio signal is transmitted, not only the line of sight direct route signal is received, but many reflections are also received at short delay intervals. These reflections could possibly be caused by a number of surrounding obstacles i.e., mountains, trees, etc. Since reflections are received with slight delay, they can cause fading or disruption of the original signal. Matched filter and correlation techniques combat the problem of multipath. Matched filters attempts to filter out the echo signals while correlation integrates all of the signals and essentially takes the average signal over a certain time slot. As a result, reliability, which is a problem in any radio network, especially when digital signals are being transmitted, is improved significantly.

b. Frequency hopping

FH spread spectrum simply requires the sender and receiver to hop synchronously from one frequency to another in a pseudo random manner [Ref. 6: p. 1475]. Again, as long as the pseudo random code is not known by the enemy, there will be little chance of jamming or detecting transmissions. One of the biggest advantages of FH is the ability to share spectrum channel capacity. Instead of having ten dedicated channels allocated to ten users that most likely will not use their channel continually, we could, for example, have fifteen users share the same ten channels, each one using a different FH code. Occasionally there may be collisions, depending on traffic intensity, but the potential for allowing more users access to the channel is obvious.

FH requires synchronization but the time slots are usually not as short as those used for PN modulation. As the slot size shortens, the complexity and cost increase. Today, synchronization at a slow rate of 10 or 20 hops per second is fairly simple and practical. Probably the most difficult obstacle to overcome for the FH spread spectrum technique is not the synchronization, but the problem of adding new members to the network. How does a new member know exactly where in the FH algorithm the network is located? One way to solve this problem is to associate time of day with the FH algorithm. There are also guessing methods which lead to the correct hopping position. As long as the basic FH algorithm is known, certain educated guesses can be made which, after a number of attempts, will position the new node's FH sequence properly. FH can also take advantage of matched filtering and correlation to reduce the impact of multipath.

FH allows voice and data traffic to share the same channel at the same time. Short packets of 1/10 of a second can hop on voice channels at the same time the channel is being actively used with minimal effects. The voice channel user will, at the most, experience a short blip in the channel; and if the packet broadcast is stronger than the voice signal, it will capture the channel without interference at the receiving packet radio. Different FH codes could also be assigned to different packet radios to reduce contention in the same way PN codes can be assigned.

In the short run, FH is simple and easy to use even though, after a few days, synchronization may become a problem. Nevertheless, it is one of the most cost effective way of dealing with packet radio contention and jamming.

IV. DESIGN

A. INTRODUCTION

To respond to the Marine Corps logistic deficiency described in chapter two, a packet radio network will be proposed as a solution. In the present chapter we will begin to design such a network. The objective of the design will be to provide the user with a means to quickly communicate a logistic demand to both the source and the chain of command, and to increase the speed of local processing by mechanizing functions. In general, our goal is to allow any unit (down to the company level) to locate a source of supply and or logistic support that can satisfy its need by just keying a few characters onto a hand-carried packet radio. The OSI network model will be used to describe the various features of this network; and although a great deal of work and experimentation are needed to adequately investigate the design details, we will try to develop a prototype to establish the feasibility of performing a more technical review.

B. NODE PROCESSING (APPLICATION LAYER)

In this section, the application layer of the packet radio network will be developed. We will also assume a network has already been established and concentrate on the processing requirements of a typical node in the packet radio network. It is also assumed the topology of the network is hierarchical, reflecting the chain of command. As such, each logistic request will flow from one level of command to the next level higher until it ultimately reaches the support element. Additionally, we will assume that each level of command does possess some support capabilities, so that a number of logistics functions are decentralized.

In order to analyze the processing needs of a node within a packet radio network that has been designed to support the logistic communication of a Marine landing force, structured analysis procedures will be utilized. A data flow diagram will indicate processing needs from a user's point of view while a data dictionary will demonstrate the required information for each type of request and a structured chart will break the process down into programmable modules.

In this section we will consider the processing of incoming packets, not the generation of packets. Functions concerning the generation of packets at the application and presentation layers include receiving keyed input, formatting the packet for transmission, and placing a copy of the packet in a pending response file. These functions will not be discussed in this section, however. Only the functions of the receiving node will be examined in this chapter.

1. Data Flow Diagram

The data flow diagram shown in Figure 4.1 demonstrates the flow of data from the time a request arrives at a node to the time it is completely processed through that node. The following paragraphs will describe the actions taken at each step of the data flow diagram.

DETERMINE ACTION simply directs requisitions to the appropriate processing function. Some requests require review, since they may be invalid or the commander may want to approve all of a certain type of demand. These requests are then sent to REVIEW. Other requisitions may not require any review and can be passed immediately while still others can be processed by the node at once. These requests are sent to PASS and TRY TO SATISFY AT ONCE respectively.

At REVIEW, a human judgement is made on the validity of the request based on the particular needs and situation at the moment. A request may be invalidated because it asks for more than the customer really needs i.e., the company commander that asks for a 50 ton crane to load a truck that can only carry 2 1/2 tons. Also, the quantity requested may be so great that such an issue would deplete the inventory, thus denying availability to another unit. If a request is invalid, a reason is provided and the demand is sent to CANC where cancellation status is sent back to the customer. This cancellation action is also recorded in the history file. If the request is valid, however, it is sent to TRY TO SATISFY AT ONCE or PASS, again depending on the judgement of the operator.

At TRY TO SATISFY AT ONCE the item or service requested is compared against on hand stocks or capabilities. If the order can be filled, available status is sent back to the customer, the requisition is recorded, the inventory adjusted, and arrangements made to pick up or deliver the item. If the item is not in stock (NIS), it is sent to REVIEW. This step is necessary in order to check the possibility of filling the demand with a substitute item or service. Also, the possibility exists that there is some simple error that may have caused the NIS status, but was not detected by the system.

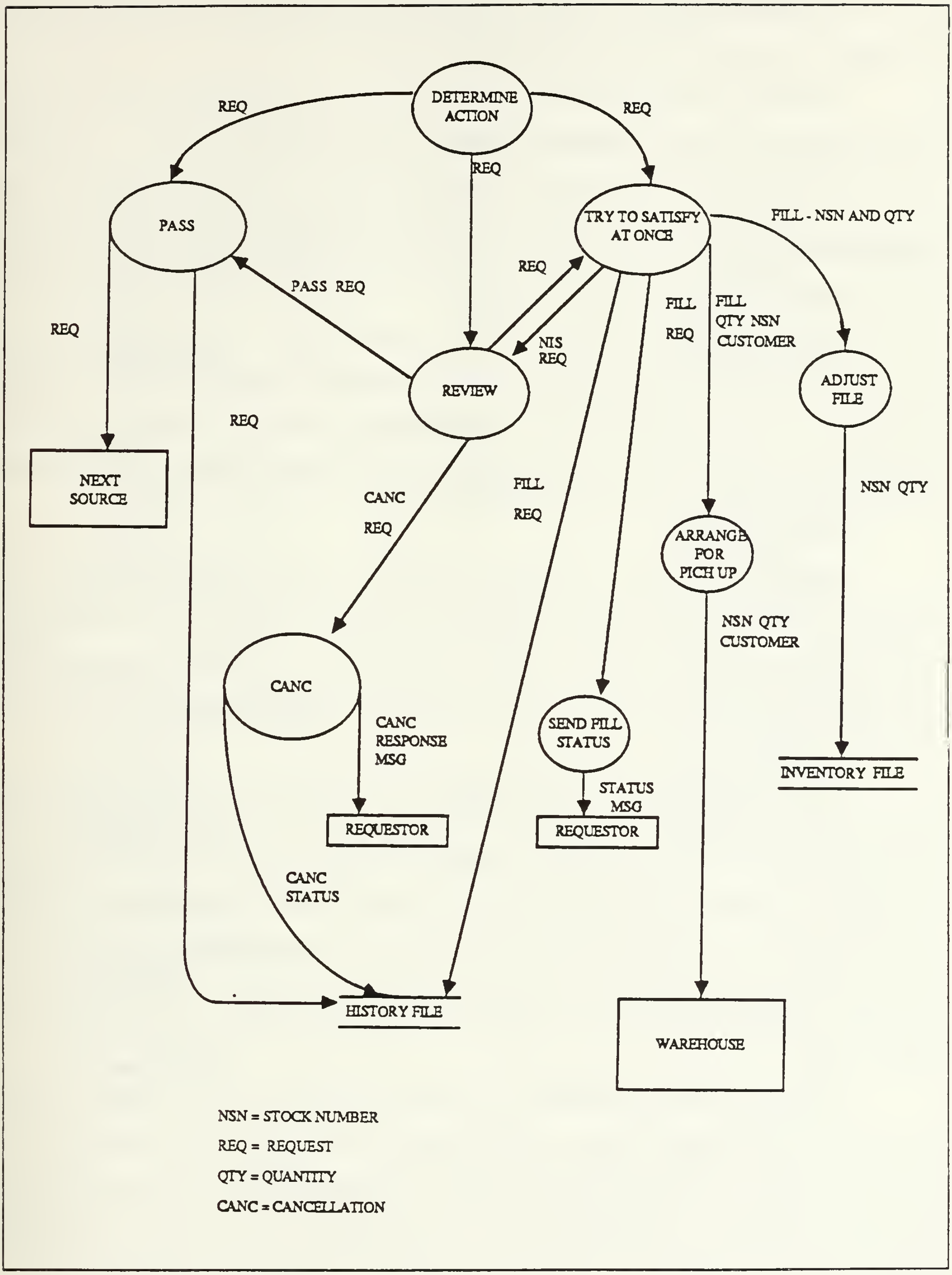

Figure 4.1 Data Flow Diagram.

At PASS, requests are simply reformatted so they can be sent to the next level of support. An entry is also made in the history file.

In order to allow requests to flow through the system described by the data flow diagram in Figure 4.1, logistics requests must be grouped in such a way that the above decisions can be made quickly. Figure 4.2 is an initial data dictionary which categorizes different type of logistics requests and lists the necessary information required for each type. They are broken down into six basic groups, some of which are broken down even further into sub-groups.

The flow of data at the node level, as shown above, is not a compex process. It simply provides a means to accept requests, search a file for availability, and pass status back to the customer. With this background in structured analysis we will now attempt to construct a system, using computer technology to accomplish some of the processing portrayed in the data flow diagram.

2. Structured Chart

Figure 4.3 contains a preliminary structured chart for a typical packet radio network node. The DETERMINE ACTION module in Figure 4.3 has been further broken down in Figure 4.4 and TRY TO SATISFY AT ONCE and PROCESS REVIEW in Figure 4.4 have been broken down still further in Figure 4.5 and Figure 4.6 respectively.

Reading Figure 4.3 from left to right, it is assumed that a packet arrives at the node via the packet radio network. The arrival of the packet initiates the GET REQUEST module. This module first interrupts any ongoing processing. It also pages in the required programs and performs error detection using data dictionary files and constraints. This error detection function checks for input errors,[9] not transmission errors which are presumed to be checked by the network. The RECORD IN HISTORY module would not be required if error detection is accomplished at the sender level.

At DETERMINE ACTION the document identifier is read in order to funnel the request to the proper module. This corresponds to DETERMINE ACTION in the data flow diagram. DETERMINE ACTION can pass requests to: PROCESS PASS, PROCESS REVIEW, PROCESS TRY TO SATISFY AT ONCE, PROCESS RESUBMISSION, PROCESS RESPONSE and PROCESS INPUT ERROR.[10]

---

[9] Input errors checks could be more efficiently accomplished by the sending node but we will show it here for demonstration purposes.

SUPPLY

REPAIR PART

Document Identifier
Priority
Document #
NSN
Quantity
Unit of Issue
Nomenclature
End item

FLOAT

Document Identifier
Priority
Document #
NSN
Quantity
Unit of Issue
Nomenclature
End Item

AMMO

Document Identifier
Priority
Document #
DODIC
Quantity
Unit of Issue

FUEL

Document Identifier
Priority
Document #
NSN
Quantity
Unit of issue
Nomenclature
Location

RATIONS

Document Identifier
Priority
Document #
NSN
Qunatity
Unit of Issue
Nomenclature
Location

MEDICAL SUPPLY

Document Identifier
Priority
Document #
NSN
Quantity
Unit of Issue
Nomenclature

SUPPLY OTHER

Document Identifier
Priority
Document #
NSN
Qunatity
Unit of Issue
Nomenclature
Remarks

Figure 4.2 Initial Data Dictionary.

MAINTENANCE

SERVICE

Document Identifier
Priority
Document #
End Item
Location
Description of problem

MOTOR TRANSPORT

PASSENGER

Document Identifier
Priority
Document #
Number of Passenger
Pick up Point
Destination
When

CARGO

Document Identifier
Priority
Document #
Cargo Description
Quantity
Pick up Point
Destination
When

ENGINEER

EQUIPMENT

Document Identifier
Priority
Document #
Item Name
Quantity
Where
When
How Long

SERVICE

Document Identifier
Priority
Document #
Service Needed
Where
When

Figure 4.2 Initial Data Dictionary.

MEDICAL

SERVICE

Document Identifier
Priority
Document #
Service Required
Remarks

PARAGRAPH

SERVICE

Document Identifier
Priority
Document #
Description of Need

Figure 4.2 Initial Data Dictionary.

Flexibility must be built into the system to allow for an easy way to redirect the flow of different types of requests at DETERMINE ACTION. As such, the system must quickly implement the wishes of the commanding officer who may, for example want to send different types of requests to REVIEW at different times.

If the demand is one that is designated to be passed at once, it is passed as quickly as possible. The F/P/C code must be set to P (indicates passing action is required). Both the request and the P code are then sent directly to READ F/P/C CODE. This particular function may be performed by programming the packet radio attached to the terminal equipment to recognize and pass certain types of demands before the packet enters the node system (at the transport layer). Thus, the PUT IN HISTORY module is shown here. This will save terminal equipment processing time.

---

[10]PROCESS RESPONSE AND PROCESS INPUT ERROR are primarily primitive level functions (performed by the node that initiates the packet) but are shown here for demonstration purposes.

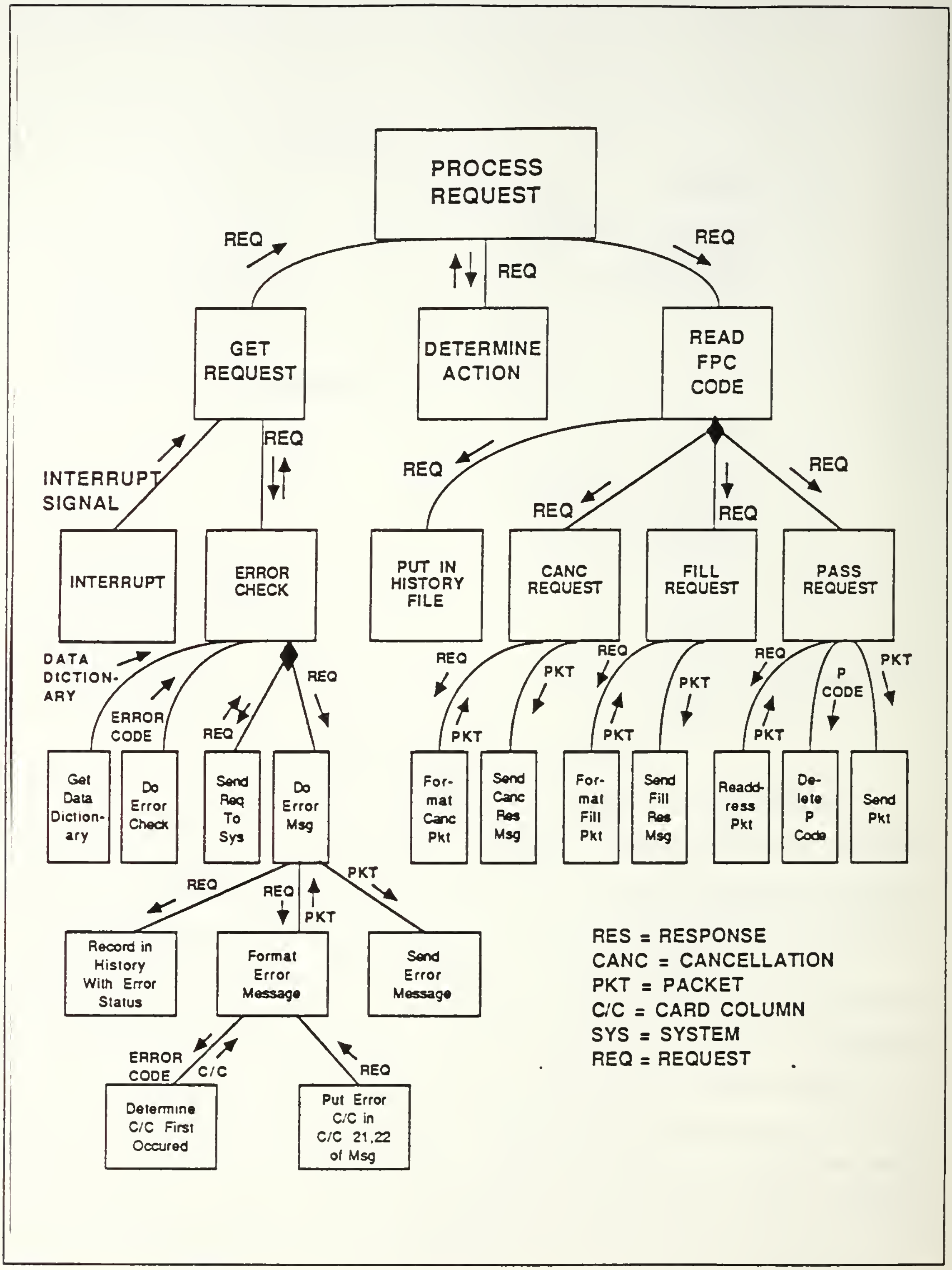

Figure 4.3 Process Request.

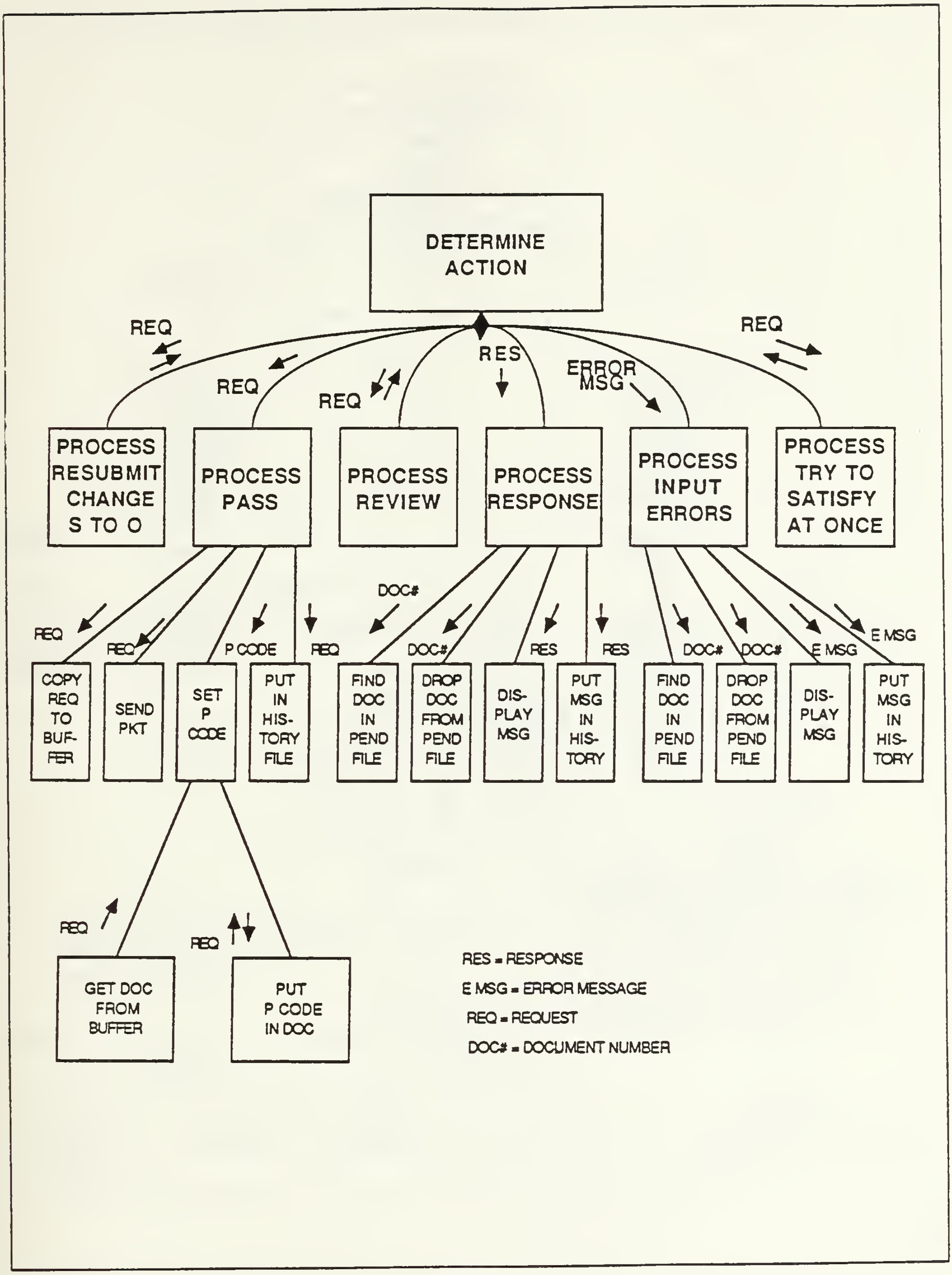

Figure 4.4 Determine Action.

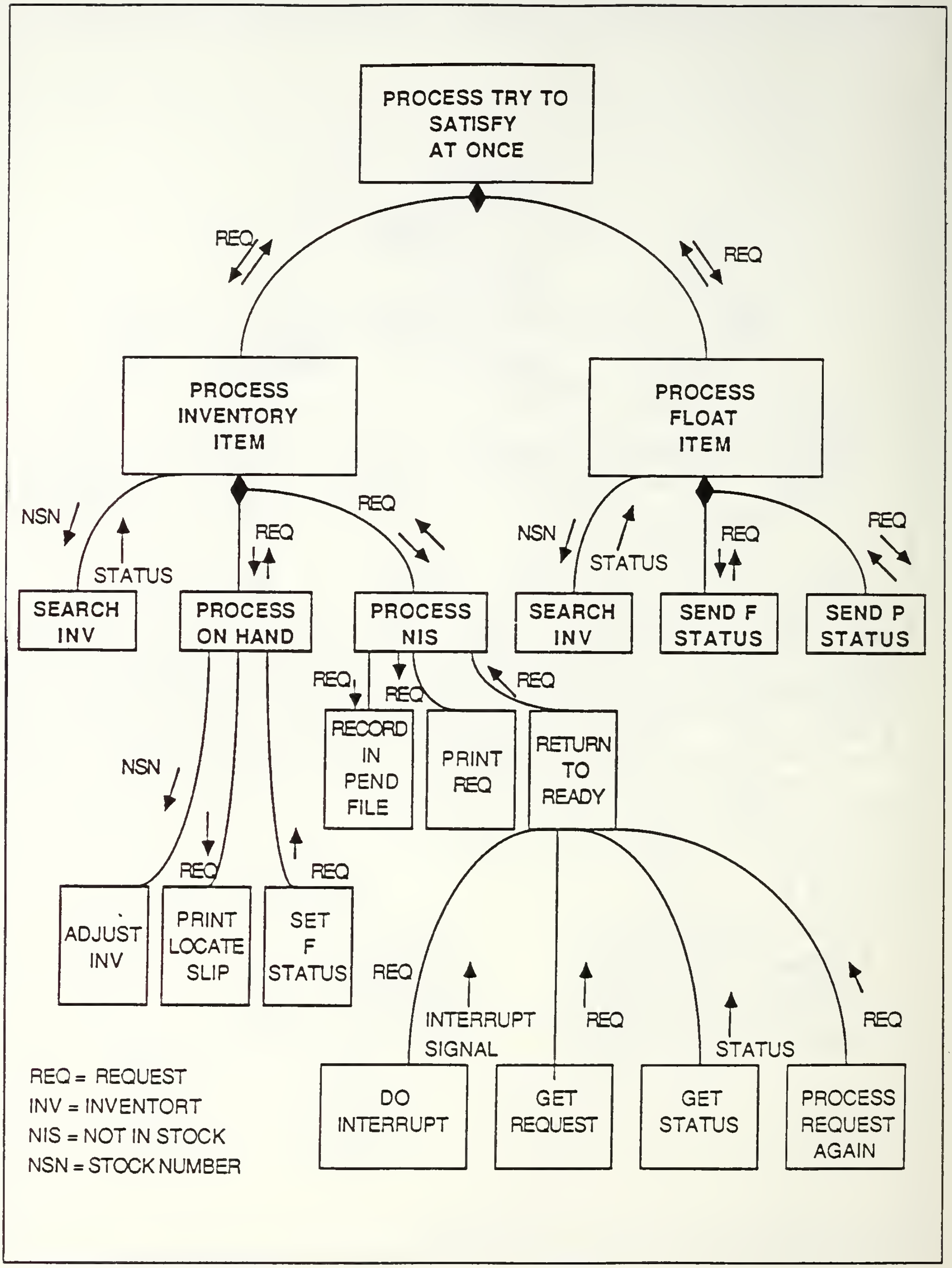

Figure 4.5 Try to Satisfy at Once.

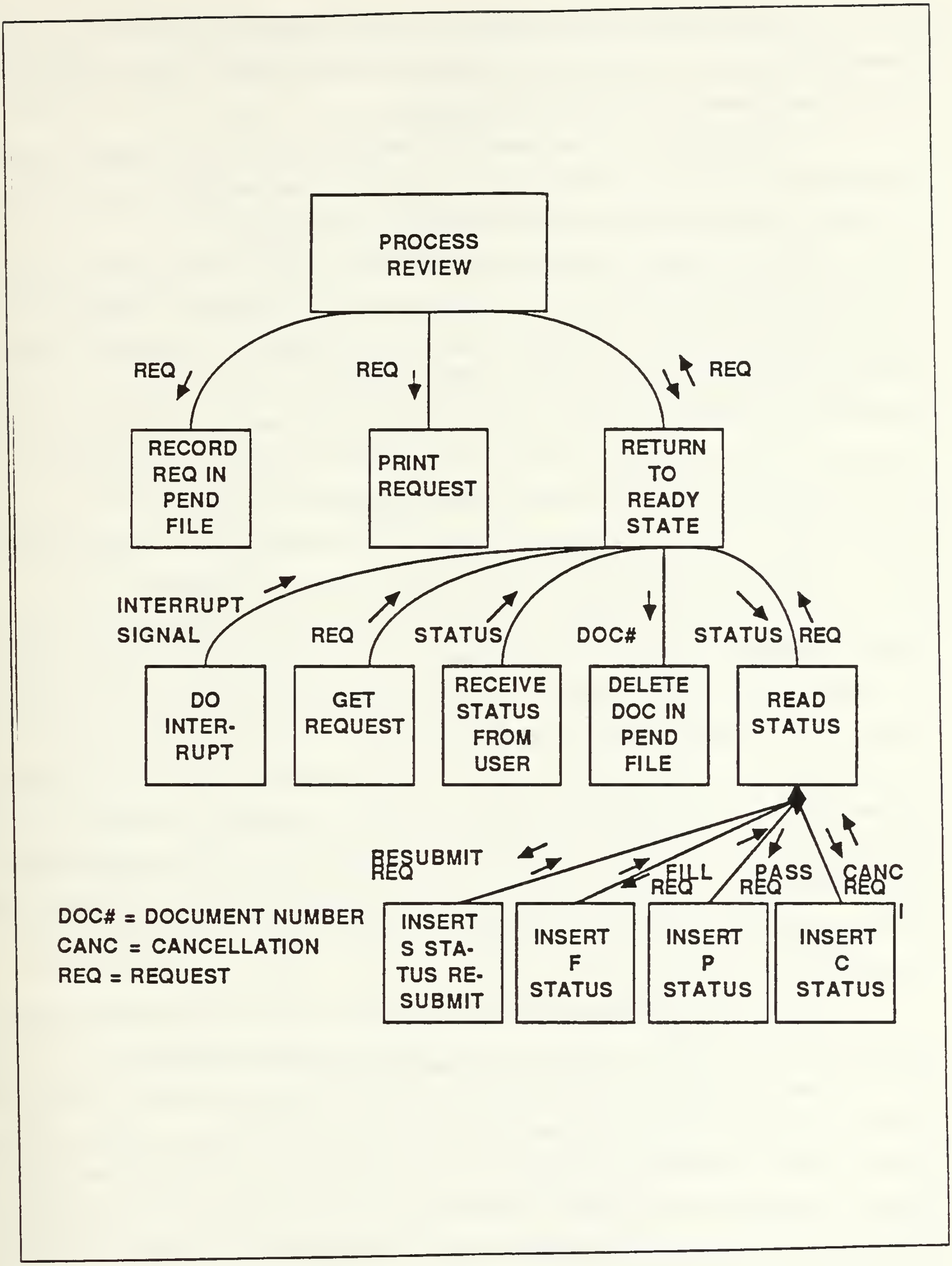

Figure 4.6 Process Review.

Requests that are being resubmitted are merely reformatted for submission through the system. This is done by overlaying card column 2 with an O and routing the transaction back to DETERMINE ACTION.

If the request is a response to a request made by that node, the pending response file must be called and the appropriate action taken (see Figure 4.4). Essentially the same process occurs with input error messages.

If the request requires review, it is simply recorded in a special pending file and displayed/printed for review (see Figure 4.6). The review is performed by an operator who considers the current situation and capabilities, then makes a decision. While this decision is being made the CPU cannot remain in a waiting state, but must return to the ready state so that other arriving packets can be processed. Once the decision is made to fill, pass or cancel, the operator will call up the pending file to the terminal screen, set the F/P/C code and if required place an explanation in the remarks field. When this is done the request is deleted from the pending file and sent to READ F/P/C. The system must respond to the operator's input interactively.

If the request is a supply requisition that does not require review, it is sent to TRY TO SATISFY AT ONCE (see Figure 4.5). When the request reaches this point, a determination is made (after reading the document identifier) to see whether the request is for ammo, medical, supply, rations, fuel, a part, or a float item. If the request is not for a float item, it is considered an inventory item and the appropriate inventory file must be searched to see if the request can be satisfied. Once the file has been searched and a match is found, the file must be reduced by the amount issued and an issue slip printed out for warehouse personnel indicating the item, the location and the customer. The F/P/C code is then automatically set to F without the aid of an operator.

If the item is not in stock (NIS), then the request is sent to PROCESS NIS. This module will record the request in a pending NIS file and display/print the request just like the REVIEW module. Again, this review will take some time, so the CPU must automatically return to the ready state. The operator will then decide to fill the request with a substitute item, pass it on to the next source of supply or cancel it. Once a decision has been made to pass or resubmit the request with a substitute item, the pending file is called. If the request is to be resubmitted, then the stock number or NSN field is replaced with the substitute and card column two is set to S which will key the request to be sent back through the system. If being passed or cancelled, the F/P/C code is set to P or C which will send the request to READ F/P/C code.

Normally requests are sent to a particular issue point and the issue point personnel respond to that request by providing the physical item. Since float items are repair parts that, themselves, can be repaired, they cannot be issued in response to a mere request from a customer. Before an issue can be made the customer has to deliver a like unserviceable to the float warehouse. However, it is sometimes possible to quicken the maintenance cycle, if it is known for a fact, before making the trip to supply, that an item is, or is not, available at the issue point. If it is not available, some other arrangement can be made (ordering the next higher assembly, for example) without wasting the time and effort required to deliver the unserviceable. For this reason, the PROCESS FLOAT REQUEST will respond to an inquiry with status, but no physical issue is made. The float inventory will be searched and status will be provided by setting the F/P/C code.

At READ F/P/C CODE the request is recorded in history, the code is read and the request is sent to the proper module. If a request has an F/P/C code of C then a response message is formed by readdressing and sending a packet back to the customer with the document identifier in card columns 1-3, a C code in card column 4 the document number in 5-18 and any remarks in 19-80. If the F/P/C code is F then a response packet is formed in a similar manner and sent to the customer with an F in card column 4. If the F/P/C code is P, the packet is readdressed to the next source of supply. The P is then deleted.

Figure 4.7 contains a detailed data dictionary of the information necessary to keep the user informed, as well as to process system data. Each request is formatted in an 80 card column structure. Since the codes used, as well as the 80 card column format, are similar to those currently used to process supply requests, little training would be necessary. This is an important factor when considering a system designed for a user with extremely limited computer processing experience.

Along with the normal processing, there should also be a quick and easy way to update files. As items are delivered, they could either be recorded on a scanner or hand written on a form in the warehouse. Increases to on hand balances, condition code changes, and the ability to add a new entry (new stock number) to a file would be necessary. Such processing must be interactive. When ready to update, an operator has to be able to call up a file and make the adjustment immediately. A database management system like dBASE III could provide this capability. Additionally, such a system could produce ad hoc reports, capable of answering almost any question [Ref. 11: pp. 101-119].

TRANSACTION FORMATS

SUPPLY

REPAIR PART

C/C	FIELD NAME	DATA
1-3	DOC ID	AOZ
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-32	NSN	N
33	BLANK	
34-35	U/I	A
36	BLANK	
37-41	QTY	N
42	BLANK	
43-44	PRI	N
45-49	END ITEM	A/N
50-80	REMARKS	A/N

FLOAT

C/C	FIELD NAME	DATA
1-3	DOC ID	AOX
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-32	NSN	N
33	BLANK	
34-35	U/I	A
36	BLANK	
37-41	QTY	N
42	BLANK	
43-44	PRI	N
45-49	END ITEM	A/N
50-80	REMARKS	A/N

AMMO

C/C	FIELD NAME	DATA
1-3	DOC ID	AOA
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-25	DODIC	A/N
26	BLANK	
27-28	U/I	A
29	BLANK	
30-34	QTY	N
35	BLANK	
36-37	PRI	N
38-80	REMARKS	A/N

FUEL

C/C	FIELD NAME	DATA
1-3	DOC ID	AOF
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-32	NSN	N
33	BLANK	
34-35	U/I	A
36	BLANK	
37-41	QTY	N
42	BLANK	
43-44	PRI	N
45-80	NOMEN/REMARK	A/N

RATIONS

C/C	FIELD NAME	DATA
1/3	DOC ID	AOR
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-32	NSN	N
33	BLANK	
34-35	U/I	A
36	BLANK	
37-41	QTY	N
42	BLANK	
43-44	PRI	N
45-80	NOMEN/REMARKS	A/N

MEDICAL

C/C	FIELD NAME	DATA
1-3	DOC ID	AOM
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-32	NSN	N
33	BLANK	
34-35	U/I	A
36	BLANK	
37-41	QTY	N
42	BLANK	
43-44	PRI	N
45-80	NOMEN/REMARKS	A/N

Figure 4.7 Data Dictionary.

OTHER SUPPLY

C/C	FIELD NAME	DATA
1-3	DOC ID	AOS
4	F/P/C CODE	A
5-18	DOC #	A/N
19-80	DESCRIB OF NEED	A/N

MAINTENANCE

SERVICE

C/C	FIELD NAME	DATA
1-3	DOC ID	MOM
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-24	END ITEM	A/N
25	BLANK	
26-32	LOCATION	
33-80	DESCRIB OF PROB	A/N

MOTOR TRANSPORT

PASSENGER

C/C	FIELD NAME	DATA
1-3	DOC ID	TOP
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-24	QTY PASS	N
25	BLANK	
26-27	PRI	N
28	BLANK	
29-39	PICK UP POINT	A/N
40	BLANK	
41-51	DESTINATION	A/N
52	BLANK	
53-60	DATE/TIME	N
61-80	REMARKS	A/N

CARGO

C/C	FIELD NAME	DATA
1-3	DOC ID	TOC
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-30	CARGO NAME	A/N
31	BLANK	
32-36	QTY CARGO	N
37	BLANK	
38-48	PICK UP POINT	A/N
49	BLANK	
50-60	DESTINATION	A/N
61	BLANK	
62-69	DATE/TIME	N
70-80	REMARKS	A/N

Figure 4.7 Data Dictionary.

ENGINEER

EQUIPMENT

C/C	FIELD NAME	DATA
1-3	DOC ID	EOE
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-24	ITEM	A/N
25	BLANK	
26-30	QTY	N
31	BLANK	
32-33	PRI	N
34	BLANK	
35-42	DATE/TIME	N
43-80	REMARKS	A/N

SERVICE

C/C	FIELD NAME	DATA
1-3	DOC ID	EOS
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-27	DATE/TIME	N
28	BLANK	
29-37	LOCATION	A/N
38	BLANK	
39-80	DESCRIB OF SERV	A/N

MEDICAL

SERVICE

C/C	FIELD NAME	DATA
1-3	DOC ID	HOH
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-21	PRI	N
22	BLANK	
23-33	LOCATION	A/N
34	BLANK	
35-80	SERVICE NEEDED	A/N

PARAGRAPH

SERVICE

C/C	FIELD NAME	DATA
1-3	DOC ID	POP
4	F/P/C CODE	A
5-18	DOC #	A/N
19	BLANK	
20-21	PRI	N
22	BLANK	
23-80	DESCRIPTION	A/N

Figure 4.7 Data Dictionary.

REDISTRIBUTION REQUEST

C/C	FIELD NAME	DATA
1-3	DOC ID	-R-
4	F/P/C CODE	A
4-80	SAME AS ONE OF THE ABOVE	A/N

REDISTRIBUTION DIRECTION

Same as original request but will have a D in C/C 2.

RESUBMISSION

Same as original request but will have a S in C/C 2.

INPUT ERROR MESSAGE

C/C	FIELD NAME	DATA
1-3	DOC ID	-E-
4	BLANK	
5-18	DOC #	A/N
19	BLANK	
20-21	ERROR CODE (C/C ERROR OCCURED)	N

RESPONSE MESSAGE

C/C	FIELD NAME	DATA
1-3	DOC ID	SAME AS ORIGINAL DOC
4	STATUS	F = FILL C = CANC
5-18	DOC #	A/N
19-80	REMARKS	A/N (OPTIONAL)

ACK

C/C	FIELD NAME	DATA
1-3	DOC ID	-A-
4-7	LAST 4 OF DOC# (SERIAL #)	N

NAK

C/C	FIELD NAME	DATA
1-3	DOC ID	-N-
4-7	LAST 4 OF DOC# (SERIAL #)	N

DELETE PKT

C/C	FIELD NAME	DATA
1-3	DOC ID	DOD
4	BLANK	
5-10	UNIT ID	A/N
11-13	MINUTES OFF NET	N

SYNC PKT

C/C	FIELD NAME	DATA
1-3	DOC ID	SOY
4-11	TIME IN .01 SECOND INTERVALS	N

COMM CHECK PKT

C/C	FIELD NAME	DATA
1-3	DOC ID	COC
4	BLANK	
5-9	UNIT ID THAT SENT DISTRESS PKT	A/N

ADDRESS PKT ADD

C/C	FIELD NAME	DATA
1-3	DOC ID	UOA
4-80	LIST OF 8 BIT UNIT ID CODES	*

Figure 4.7 Data Dictionary.

```
     ADDRESS PKT SUBTRACT

  C/C      FIELD NAME    DATA
  1-3      DOC ID         UOS
 4-70      LIST OF 8 BIT
           UNIT ID CODES *


A = LETTER
N = NUMBER
A/N = COMBINATION OF LETTERS AND NUMBERS
* INDICATES WILL REQUIRE A CONVERSION PROGRAM TO TRANSLATE UNIT
ID CODES TO 8 BIT NETWORK UNIT ID CODES.  THIS WILL ALLOW MORE
UNITS PER PKT.


                                 CODES


ALL QTY - ALLOWANCE QUANTY

C/C - CARD COLUMN

CONDITION CODE (COND CODE) - IDENTIFIES THE SERVICEABILITY OF
   ITEM
   A - ASSETS ON HAND
   M - ASSETS IN MAINTENANCE

DATE - ALWAYS JULIAN DATE

DOCUMENT IDENTIFICATION (DOC ID)
   AOZ - PARTS REQUEST
   AOX - FLOAT REQUEST
   AOA - AMMO REQUEST
   AOF - FUEL REQUEST
   AOR - RATIONS REQUEST
   AOH - MEDICAL SUPPLY REQUEST
   COC - COMM CHECK PKT
   DOD - DELETE PKT
   EOE - REQUEST FOR ENGINEER EQUIPMENT
   EOS - REQUEST FOR ENGINEER SERVICE
   HOH - REQUEST FOR MEDICAL SERVICE
   MOM - MAINTENANCE REQUEST (CONTACT TEAM)
   POP - REQUEST FOR LOGISTIC SUPPOERT NOT CATEGORIZED ABOVE
   SOY - SYNC PKT
   TOP - REQUEST TO TRANSPORT PERSONNEL
   TOC - REQUEST TO TRANSPORT CARGO
   UOA - ADDRESS PAKT ADD
   UOS - ADDRESS PKT SUBTRACT
```

Figure 4.7 Data Dictionary.

```
    CHANGE O TO S IN C/C 2 TO RESUBMIT (OF DIC)
    CHANGE O TO E IN C/C 2 FOR ERROR MESSAGE
    CHANGE O TO R IN C/C 2 TO MAKE A REDISTRIBUTION REQUEST
    CHANGE O TO A IN C/C 2 TO ACK
    CHANGE O TO D IN C/C 2 TO MAKE A REDISTRIBUTION DIRECTION
    CHANGE Ø TO N IN C/C 2 FOR NEGATIVE ACKNOWLEDGEMENT

DOCUMENT NUMBER
   FIRST 5 DIGITS - UNIT IDENTIFICATION CODE (USED CURRENTLY)
   NEXT 4 C/C DATE
   LAST 5 C/C SERIAL NUMBER TO INDICATE THE NUMBER OF REQUESTS SO
     FAR THAT DAY. THE FIRST DIGIT OF SERIAL NUMBER WILL BE:
       T - MOTOR TRANSPORT
       E - ENGINEER
       M - MAINTENANC
       H - MEDICAL
       A - AMMO
       R - RATIONS
       X - FLOAT
       F - FUEL
       S - OTHER SUPPLY
       P - ANY OTHER

DODIC - 6 CHARACTER CODE USED TI IDENTIFY AND STOCK AMMO

END ITEM NAME - PREFER TAM NUMBER FOUND IN THE TABLE OF
   AUTHORIZED MATERIAL OF MARINE CORPS

F/P/C CODE - STATUS CODE
   F - FILLED
   P - PASS TO NEXT SOURCE
   C - CANCELED

LOCATION NUMBER - NUMBER USED BY WAREHOUSEMAN TO FIND ITEMS

LOT NUMBER - NUMBER IDENTIFY LIKE ITEMS THAT COME FROM THE SAME
   MANUFACTURE AT THE SAMEN TIME

NSN - NATION STOCK NUMBER ASSIGNED TO ALL MILITARY EQUIPMENT AND
   PARTS.

PICK UP/DESTINATION POINT - COORDINATES OR DESCRIPTIVE WORDS

PRIORITY (PRI) - CODE FOUND IN MILSTRIP PUBLICATIONS
   Ø1
   Ø2
   Ø3
   Ø4
   Ø5
   Ø6
   Ø7
   Ø8
   Ø9
   1Ø
   11
   12
```

Figure 4.7 Data Dictionary.

QTY - QUANTY

SUB NSN - SUBSTITUTE ITEM

U/I - UNIT OF ISSUE

FILES

ALL PENDING FILES - 80 CHARACTER REQUEST
HISTORY FILE - 80 CHARACTER REQUEST AND ERROR CODE FIELD (2 CHARACTERS)

PARTS INVENTORY

NSN	13	CHARACTERS (KEY)
QTY	5	CHARACTERS
U/I	2	CHARACTERS
ALL QTY	5	CHARACTERS
SUB NSN	7	CHARACTERS
LOCATION	10	CHARACTERS

FUEL INVENTORY

NSN	13	CHARACTERS (KEY)
QTY	5	CHARACTERS
U/I	2	CHARACTERS
ALL QTY	5	CHARACTERS
NOMENCLATURE	7	CHARACTERS
LOCATION	10	CHARACTERS

RATIONS INVENTORY

NSN	13	CHARACTERS (KEY)
QTY	5	CHARACTERS
U/I	2	CHARACTERS
ALL QTY	5	CHARACTERS
LOT NUMBER	7	CHARACTERS
LOCATION	10	CHARACTERS

FLOAT INVENTORY

NSN	13	CHARACTERS (KEY)
QTY	5	CHARACTERS
U/I	2	CHARACTERS
ALL QTY	5	CHARACTERS
SUB NSN	7	CHARACTERS
LOCATION	10	CHARACTERS
COND CODE	1	CHARACTER

AMMO INVENTORY

DODIC	6	CHARACTERS (KEY)
QTY	5	CHARACTERS
U/I	2	CHARACTERS
ALL QTY	5	CHARACTERS
LOT NUMBER	5	CHARACTERS
LOCATION	10	CHARACTERS

MEDICAL INVENTORY

NSN	13	CHARACTERS (KEY)
QTY	5	CHARACTERS
U/I	2	CHARACTERS
ALL QTY	5	CHARACTERS
SUB NSN	7	CHARACTERS
EXPIRE DATE	4	CHARACTERS
LOCATION	10	CHARACTERS

Figure 4.7 Data Dictionary.

A batch reorder process would also be required that would simply compare on hand quanties to stock allowance quanties and format a reorder request for the difference. There is no need to establish complicated reordering criteria at this level.[11]

A follow up or request modification scheme, for simplicity, has not been included in the node processing design. However, these additional functions could be implemented by changing the O in card column 2 of the original requisition to T for a follow up or M for a modification. Once received follow up and modification transactions would be compared against the history file and the appropriate action taken. Follow ups would be submitted as a request through the node system if no match was found in the history file.

C. NODE HARDWARE REQUIREMENTS

The Marine Corps has currently provided IBM Series 1 mini computers to all units down to the battalion level. The Series 1 that the Marine Corps purchased is small and rugged. It has a memory capacity of 128K RAM. The execution cycle time varies from 660 to 900 nanoseconds with one channel available [Ref. 12: p. 117]. Could this computer accomplish the processing required for a node in the packet radio network described previously? This possibility will be explored in the following paragraphs.

1. Terminal Equipment Utilization

Since each node would have to be ready to process at all times, its data processing equipment must be dedicated to network applications. Terminal equipment at lower echelons may then be underused and units may not be able to use their data processing capabilities for other applications. However, software could be provided that would cause an interrupt of other application programs and page in network programs. The Series 1 computers then would not have to be entirely dedicated to the packet radio network.

2. Processing Speed

The question of speed is not of great concern to the user. This system is not required to be real-time but is an inquiry system that can wait for an answer involving a human decision. The only immediate response needed is one that insures the packet was transmitted and received properly which is provided by the data link layer. The status response, indicating whether or not the request was filled, could be provided

[11] Allowance computation will not be addressed here.

within five or ten minutes. This may seem like a long time in data processing terms but it is far superior to the days of delay currently experienced.

It is difficult to compute how long it will take to process a request and provide status back to the customer without actually writing the programs and without knowing the programming language used. It seems reasonable, however, to assume that the computer processing will not take longer than the required five minutes. The greatest delay, of course, will be caused by the operator making the decisions.

Another factor that must be considered is the traffic density. Will queues of packets develop at network nodes waiting for terminal equipment processing? To answer this question we must analyze the expected traffic and the service or processing time. In order to perform this analysis, we will examine a "worst case" scenario. Basing our analysis on a ten hour day, then taking current garrison supply operations and multiplying this by two and one half for combat operations, we can estimate the number of requests generated per minute for the largest type landing force.[12] These figures are contained in Table 2 and are developed for the central node where all requests are sent if they are not filled at a lower echelon. In other words, only one node in the entire landing force would actually be this busy. These data do not include redistribution, response and error traffic, however. What we have done here is to use extremely high estimates to demonstrate a method for solving this problem and to gain a general sense of the problem. Therefore, it is realized that more in-depth study is required to produce more precise estimates.

There are six routes that a packet can take once it arrives at the node system: PASS, REVIEW or TRY TO SATISFY AT ONCE, PROCESS RESPONSE, PROCESS PROCESS ERROR MESSAGE and PROCESS RESUBMISSION. Since this is the final local source and since all requests must be processed through REVIEW before they get to PASS at this node we will ignore PASS. We will also ignore PROCESS RESPONSE AND PROCESS ERROR, since these are primarily primitive level functions.[13] PROCESS RESUBMISSION will be ignored because this traffic is expected to be light. Also, for the sake of simplicity, redistribution traffic is not considered. In TRY TO SATISFY AT ONCE, since the parts inventory will be much larger than the other inventories and will cause a longer search time, we will treat parts

[12]Figures obtained from official Marine Corps records maintained at Headquarters Marine Corps (MAF total monthly demand rate).

[13]Functions performed by the node that generates the request.

TABLE 2

HIGHEST REQUEST RATE EXPECTED

Transaction Type	Number / Minute
Supply Parts	7
Supply Float	1/3
Supply Other	1/6
Supply Rations	1/3
Supply Fuel	1/3
Supply Medical	1/6
Supply Ammo	1
Maintenance	1/6
Engineer	1/6
Medical	1/6
Paragraph	1/6
Motor transport	1/6

requests separately from the others. Now there are three routes: REVIEW, TRY TO SATISFY AT ONCE (PARTS REQUEST) and TRY TO SATISFY AT ONCE (OTHER SUPPLY INVENTORY REQUESTS). Some processing time constraints may now be established in terms of program micro instructions. Knowing the rate of arrival for each possible route in terms of one minute, or 60 seconds, we can develop the following formula:

$$7P + (2\ 1/3)S + (4\ 1/3)R < 60$$
$$P,S,R < 60$$
$$P,S,R > 1$$ [14]

The P is the maximum time required for processing a part requisition and seven per minute is the maximum rate at which these requisitions will enter the system. The S is the maximum processing time required for ammo, rations, float, fuel, medical, and 'supply other' requisitions and 2 1/3 per minute is the arrival rate for these requisitions. The R is the maximum time for processing a review type requisition and from Table 2 and 5/6 is the rate these requisitions will enter the system. However, it is

[14] Interrupts will cause an estimated 1 second delay regardless of program processing time. At this busy central node the assumption is made that network programs would remain in memory and not require paging.

estimated that 50% of the parts requests will be NIS, so 3.5 (7/2) will have to be added to the 5/6 which gives 4 1/3 transactions per minute for R.

This formula is only useful in the situation where the arrival rate will never be greater than that shown in Table 2 previously. Thus, no queues will develop since the processes can accommodate the highest expected arrival rate. P, S and R could, of course, be any value less than 60 and greater than 1, but let us adjust some values to get an idea of the processing constraints described by this formula.

Let us say P = 5 seconds, S = 3 seconds and R = 4 seconds. The result is 59 1/3 seconds and it takes 1 second to do interrupts for I/O. Or put another way, considering it takes 900 nanoseconds to execute a micro instruction, then each process is limited to 4.44, 2.22 and 3.33 million micro instructions respectively.[15]

The "worst case" approach is used to analyze this problem because the traditional queuing model is highly dependent on an average arrival time normally based on the poisson distribution. In this problem the average has little meaning, since the variance of the average is extremely high and extremely dependent on the environment. An unopposed landing will have a much different requisition rate than an opposed landing, the weather will be an especially dominating factor, etc.

If this speed does not allow enough instructions to accomplish the required processing, there is the possibility of using two IBM Series 1 machines at this final source of supply. As packets arrive at this central site, they would be segregated immediately upon arrival by the packet radio. Let us say each Series 1 was hardwired to the packet radio and all the P transactions were routed to machine A and the others were routed to machine B. The formula now is:

$$
\begin{aligned}
7P &< 60 \\
(2\ 1/3)S + (4\ 1/3)R &< 60 \\
P,S,R &< 60 \\
P,S,R &> 1
\end{aligned}
$$

[15]It is realized that the instruction execution rate is dependent on many factors but this provides a rough estimate of the required program size.

Now P could be as high as 8.57 seconds and S and R could be as high as 10.5 and 8.19 seconds respectively.

Four machines could also be used. Machine A would process all the S transactions. Another machine, machine B, could process all the P transactions with a stock number (NSN) above a certain number. Machine C would accept all P transactions with NSN's below a certain number and machine D would process all the R transactions. Of course, the inventory would have to be divided between two machines, but this could be easily done and would reduce search time. This would increase P to a maximum of 17.14 seconds. It would also require more from the packet radio, requiring it to read and discriminate the first digit of the NSN, which would not be a complex task. These time constraints, subtracting one second for interrupts, would allow 27, 14, and 18 million micro instructions for S, R, and P type transactions respectively. These figures seem to be within limits for this relatively simple programming task and extra minicomputers are available in the Marine Corps inventory for this busy central node.

The IBM 4341 DFASC could be used as a back up to increase processing speed. Although the IBM 4341 is much faster, the logistic network probably could not expect help from the DFASC, since it has already been assigned a number of other tasks. However, it is available for use during a critical situation and should be prepared to back up the logistic network on short notice.

Also, by decentralizing support (providing it closer to the customer), more demands would be filled at a lower level lessening the load on the central node. Restock or replenishment requisitions, which eventually result from issues done at a lower echelon, would be batch processed and sent to the central node during a slow period at night. This would reduce the packet arrival rate, which would decrease the probability of an explosive queue problem. Decentralization, however, will increase the amount of redistribution requests. Because a redistribution response is required from each individual source, this processing will take time away from normal traffic. The disadvantages of decentralization, therefore, may outweigh the advantages.

3. Memory

Memory is another important consideration. The Series 1 has only 128K of RAM memory. If a dBASE III program was used it could not fit on a 128K machine. dBASE III requires 256K of memory, which means another solution would be necessary [Ref. 11: p. 197]. Perhaps a simple direct access file using links could be programmed or bought off the shelf, or the Series 1 memory could be expanded to process the database. Another option is to write the proper software that would implement a virtual memory. Additionally it is estimated that about 20,000 inventory records would be maintained by a MAF. However, these records could be distributed to many issue points and computers so that no more than 2,000 records would be maintained on any one computer.

The Marine Corps is contemplating the purchase of Zenith Z248 computers as replacements for the Series 1's. This machine has 512K of memory and can run dBASE III. The Z248 could also cope with the demands of this logistic packet radio system and probably process demands quicker than the Series 1.[16]

4. Interrupt Architecture

The interrupt structure is another important consideration of a packet radio. For example, the ALOHANET is an interactive real-time system. Developed at the University of Hawaii, the ALOHANET linked terminals to an IBM 360 via an HP 2100 front end computer from geographically distant areas [Ref. 5: p. 203]. The same type of interrupt structure used in the ALOHANET could possibly be implemented on either the Series 1 or the Z248.

D. SUMMARY

It seems quite possible to implement the logistics system described in this thesis with the computers already fielded in the Marine Corps. An expanded memory and some system programming may be required , but this could be less expensive than trying to outfit the Marine Corps with a new computer. Additionally the cost of the packet radio repeaters would be reduced, since the keyboard and display functions could be performed by the terminal equipment. An interrupt and paging software package would also allow the use of other data processing applications during the time the processor waits for packets. While the complexities of compatibility require more research, the IBM Series 1 seems to be a plausible option.

E. NETWORK DESIGN

This section of the chapter will address the design issues related directly to the packet radio network. It will be assumed that the nodes of the network are designed in accordance with the previous section. Such characteristics as topology, security,

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[16]Verified by phone conversation with Maj. Robert Brown HQMC Procurement Headquarters Marine Corps Procurement, 27 Aug. 1986

packet structure, error checking, radio connectivity, protocol and routing will be described herein.

1. Topology (Network Layer)

Since there is an established need for the chain of command to be aware of (and in some cases approve) logistics requests, a hierarchical topology seems to be the most appropriate for this application. The only other reasonable choice for this particular situation is to centralize support and require all nodes to request support directly from this central activity. There are, however, several disadvantages to this star topology approach. First of all it is not desirable to centralize support in a combat environment because if the support activity is destroyed, all support will be lost. Support should be distributed, as much as possible, to provide a more survivable structure. Since transportation is at a premium during an amphibious landing, it is important to position support as close to the customer as possible. A hierarchical topology provides the capability to distribute support among different layers of the hierarchy thereby providing logistic support close to the customer.

Another disadvantage to the star topology approach is that reliability and security are likely to suffer. In a mobile situation the physical geography of a particular location may prevent direct access to the central activity. For example, a mountainous or jungle area may not allow line of sight communications. Later it will be shown that line of sight communications are necessary for packet radio operations. In order to maintain network integrity some sort of repeater structure would probably be required. It may prove difficult to choose an appropriate repeater structure, especially in a dynamic situation. On the hand, by nature, the hierarchical topology provides a predictable repeater structure. In case repeaters were not used, transmission power would have to be high enough to reach the central activity; higher than that required by a hierarchical topology in order to reach the next level in the chain of command. The higher the transmission power, the greater the chances of the enemy being able to detect and disrupt the channel.

A hierarchical topology also has disadvantages. It will increase the number of hops a packet must make to arrive at its destination. As the number of hops increase the delay time will be magnified, but, since the user does not expect real-time responses, delay is not a significant factor in this situation. Traffic, too, will increase as a result of multiple hops; but judging from an initial scan of the expected maximum request rate developed in the last section, there seems to be plenty of bandwidth available so throughput will not suffer from the added traffic. This will be discussed in more detail when the protocol issue is addressed.

To briefly recap the hierarchical approach, the deciding issues are: the need for distributed logistic support for survivability, the need to position support as close to the customer as possible, the need for higher echelon approval and information, the need for a predictable repeater structure, and the reliability and security factors in a dynamic environment. For these reasons, the hierarchical topology is deemed most appropriate. Figure 4.8 is a hierarchical diagram of a typical logistic network designed to support a MAF.

2. Routing (Network Layer)

With a hierarchical topology the problem of routing is taken care of automatically. All traffic will flow smoothly from the lower to the higher levels via a set chain of command; and higher levels will be programmed to accept only the packets of its assigned subordinates. As a result, no address is required on the packet, only the sender's identification is needed. This structure simplifies the problem of routing for packet radio networks, especially those that are highly mobile. Movement is a problem for most hierarchical networks because a node's movement will require the node to be assigned to different hierarchical routes. But movement in a military operation is normally done within a hierarchical group. A unit will nearly always submit requests to the same higher echelon node, thus movement is dynamic while routing is static. For example, generally, a battalion will not be assigned to different regiments during an operation. The battalion will move a great deal but it will move with, and not away from, its regiment.

In this case the tradeoff is flexibility, since two nodes on the same level cannot talk directly to each other. There is no stated requirement, however, for two nodes on the same level to communicate logistic information. When logistic support is needed, the proper way to ask for it is to send a request to the source and not to your neighbor. Even if your neighbor has something you need, it is still possible to go up one level in the chain of command and request a redistribution of the needed asset.

The most serious problem with this routing scheme is its robustness. If one link in the chain of command is disabled, there is no way to get around that particular link. As such, all nodes below the disabled one are cut off from higher levels of support. Obviously this is an unacceptable situation and a procedure must be found that allows a packet to flow around unserviceable links.

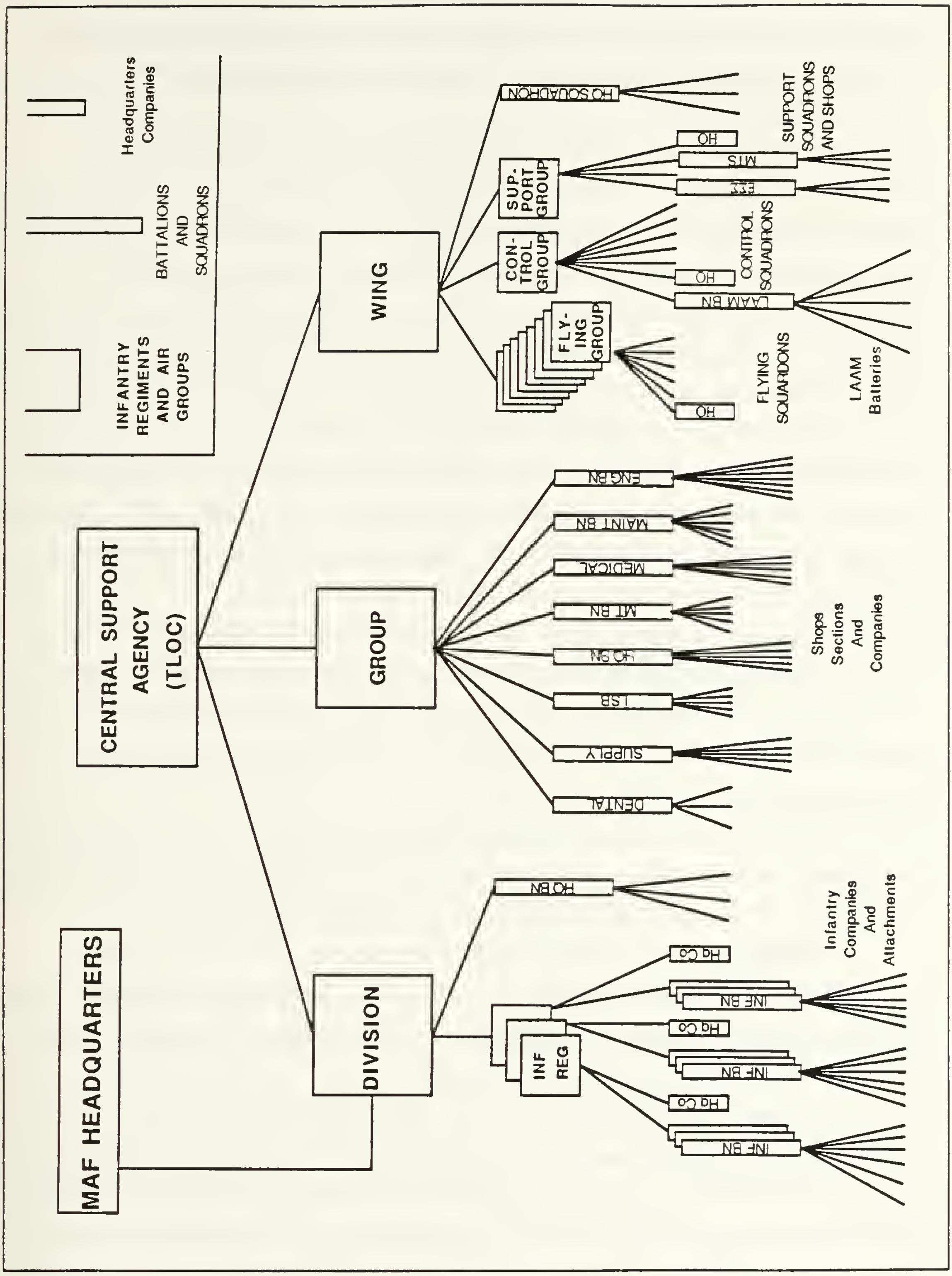

Figure 4.8 Proposed MAF Logistic Structure.

One approach to this dilemma may be to use packet radio broadcast capabilities and send the packet to all nodes within radio range and ask them to relay the packet around the failed node. For the time being, let us call this a distress packet. We could accomplish this by placing a "one" in a special bit, probably the first bit of the packet. If this bit was a "zero", then the packet would be disregarded, unless the sender was assigned to that node. However, if the bit was a "one" then each node receiving the request would relay it via its chain of command to the central support activity (TLOC). At this point, the logistic request could be honored and the TLOC would be made aware of the problem. The terminal equipment could be programmed to display the sender's address within the distress packet so that it could be determined which route contained the break in connectivity. A trace, or communications check packet could then be initiated by the operator to proceed as far as the unserviceable link and report back, thus indicating the problem location. Action could then be taken to reorganize the logistic hierarchy to allow those nodes that were cut off to be reassigned to other senior nodes. The procedure for reassigning addresses will be discussed in the network control section.

Request packets flow up the hierarchy, however, response and acknowledgment packets flow down the hierarchy. Thus, in addition to a distress bit a routing bit is necessary which will indicate that the request is being sent to the next higher or the next lower level. This will insure that transactions travel in the proper direction through the network.

In conclusion, the use of distress bits allows packets to be routed via the chain of command to satisfy user needs for command and control as well as for decentralized support, but it also allows for flexible routing to improve robustness.

3. Security

Security is an extremely important consideration for this particular application; not necessarily because the network is carrying classified data, but because packet radio is highly vulnerable to jamming.

As mentioned in Chapter Three, there are two ways to combat packet radio security problems using spread spectrum techniques. One is PN modulation and the other is FH. Both require synchronization, but PN is more complex requiring highly sophisticated radios which may make the network cost unacceptable. On the other hand, the synchronization required for FH can coincide with the synchronization needed to implement the multiple access protocol. Thus, the network synchronization could perform two functions, one for security and the other for network protocol. The only added costs of FH would then be the cost of a mechanism installed in the radio to change frequencies at specific intervals, plus the memory and logic to implement the FH algorithm.

FH can still take advantage of channel sharing. As previously pointed out a data packet can use a frequency close to the frequency used by an analog voice channel with minimal effect on voice communication. Let us say, for instance, that there were 200 voice channels and packet transmission time was 1/10 of a second. This would cause a 1/10 of a second blip to be heard on the voice channel every 20 seconds. This is assuming that the packet radio network is using 100% of the available time slots, which is most improbable, given that input is keyed in and there are, at most, only 210 nodes in this application. By setting the frequency a little higher or lower than the voice analog channel, the impact would be minimized and the packet would be able to capture the channel, insuring reception by the destination packet radio. As a result of this capture phenomenon a large number of channels do not have to be allocated exclusively for digital FH communication. In some cases it may be that no unique frequencies need to be assigned to the packet radio network. Although FH may appear to waste a fair amount of radio spectrum, in reality, if employed properly, it may save radio spectrum.

As mentioned earlier, other security measures can also be implemented. Reducing the power of transmissions to reach only the next higher level of hierarchy, for example, leads to improved security. Keeping packets as short as possible is another security measure to be considered. Basically, all aspects of the network should contribute to reducing transmission time and transmission power.

There is also the possibility of assigning different FH algorithms to different parts of the hierarchy. This would make it even more complex for the enemy to jam the entire network. If by chance the enemy was able to decipher one FH scheme they could only shut down part of the network. What happens, though, when a distress packet is transmitted while different sections of the landing force are hopping on different FH algorithms? Only those nodes on the same FH algorithm will hear the distress packet. This fact may prove advantageous, however, since one of the problems with a distress packet is that every node that hears it will retransmit the packet up through the chain of command. Essentially this results in flooding the network, but if only those nodes on the same FH algorithm hear the distress packet then the flooding will be reduced by a factor of the number of FH algorithms used. Let us say that the division, wing, and support group are each assigned different FH algorithms. The use of multiple FH algorithms will allow distress packet flooding to be limited to the major landing force elements.[17]

The structure now envisioned is one in which the wing, the division, and the support group units send packets in accordance with unique FH algorithms. Once received at the major element headquarters, the packets are retransmitted in accordance with a fourth FH algorithm to the TLOC. This also allows the major element headquarters to send distress packets.

The disadvantage of a multiple FH structure is that it is less likely a distress packet will be heard. There is, however, one possibility that may help to avoid this distress packet problem. All the FH algorithms used by the network could be stored in each node. If a node does not receive an acknowledgment to a distress packet using its FH algorithm, it could try to send the distress packet on one of the other FH algorithms. Of course this would require more memory within the packet radio, but storage capacity has become inexpensive enough so that this may be a cost effective option.

Another problem with multiple FH algorithms in a hierarchical network is that added capacity must be placed at the node where the FH algorithm initiates. In the example described above, the node at the division headquarters must be able to send and receive in accordance with the division FH algorithm. It must also be able to send and receive in accordance with the FH algorithm used on the link between the major elements and the TLOC. The only way this can be accomplished is to position two packet radios at each of these nodes.

This scheme is ideal for a typical MAF landing force, providing a typical, textbook, MAF landing force is ever employed for an actual operation. MAF's, MAB's and MAU's are rarely organized strictly by the book and real world constraints prevent perfection. And, although this scheme may seem logical, it may not fit every situation. Flexibility must be provided to the user that allows for easy adjustment of the FH structure. Perhaps one FH algorithm will suffice. In another situation five or six may be necessary. There is a tradeoff to consider in making this decision. As the number of FH algorithms increase, the amount of equipment and complexity required at certain nodes would increase. On the other hand, the more FH algorithms the more

[17]The major elements are the division, wing and support group.

difficult it will be for the enemy to detect and jam the network. Also, as will be demonstrated in the next section, the more FH algorithms, the greater the capacity of the network.

4. Multiple Access Protocol (Data Link Layer)

As mentioned previously the synchronization required by the frequency hop algorithms could be used to implement the network protocol. The traffic analysis in the node processing section (see Table 2) indicated an approximate maximum arrival rate of 10 1/6 packets every minute during the busiest period. This translates into about one packet every 6 seconds. Let us assume a packet transmission time of 1/10 of a second and that each packet must travel 5 hops, each of which requires a short acknowledgment, a response and an acknowledgment to the response with a transmission time of about 1/50 of a second. One packet, therefore, will use .8 seconds every 6 seconds. At this rate, about 13.3% of the bandwidth is being used (assuming no retransmissions due to transmission errors).

The above data seems to indicate that a simple unsynchronized protocol such as Pure ALOHA would suffice. However, we ought to make use of the synchronization provided by FH. Additionally, the figures used here are only rough estimates and should be treated as such. In view of this, a protocol that provides as much throughput cushion as possible should be chosen. The added capacity of a synchronized protocol will compensate for any arrival rate estimation errors. For security reasons, channel use should also be kept to a minimum. Pure ALOHA, by nature, will cause a greater number of collisions than any other protocol which means channel use per transaction is high and security suffers. A network design to support a Marine landing force must be highly mobile. Pure ALOHA, which was designed for a stationary fixed environment, may be unpredictable when applied to a dynamic situation. Lastly, there should be room for expansion. In the future, the network may be used to transmit different types of data to support other systems. The protocol should anticipate such changes and at best Pure ALOHA uses only 18% of the bandwidth. For these reasons a more structured and predictable protocol may be necessary.

Slotted ALOHA, on the other hand is more structured, makes use of synchronization, and provides double the capacity of Pure ALOHA. However, Slotted ALOHA has also been designed for a stationary situation, and dynamic movement may decrease throughput (in unpredictable ways) especially in a combat environment.

The fact that acknowledgment traffic is not considered when optimal throughput is computed makes the results of this theoretical analysis suspect for practical applications. Slotted ALOHA also allows nodes to transmit at the beginning of any slot, making it doubly unpredictable. Furthermore, collisions are still numerous. In optimal Slotted ALOHA each packet is transmitted an average of 2.7 times [Ref. 4: p. 237]. This fact alone may cause a security problem. Although Slotted ALOHA is simple and inexpensive, it may be necessary to choose a protocol that will maintain more control over the network traffic.

Time division multiplex or TDM may provide the degree of control we are looking for in this application. TDM reserves specific time slots for each member of the network. As a result, the probablity of packet collisions is reduced to almost zero. Retransmission of packets is kept to a minimum, providing better security and more predictability.

The problem with TDM is that the more nodes there are on the network, the longer the delay before transmission. For example, it is estimated that 210 packet radios are required to support a MAF. If the packet transmission time was 1/10 of a second, each terminal would have an opportunity to transmit every 21 seconds. If a transmission error occured, then the node would have to wait another 21 seconds before it could retransmit the packet. Twenty seconds is a long time in network terms. Although it probably will take more than 20 seconds to key in the next request, there is no room for transmission error. The network should be a good deal faster than the input rate so the user never has to wait for the network before submitting requests. Also, at higher echelons of the hierarchy a backlog would be created since these nodes must transmit the requests received from all their subordinates. How then can this time be shortened? Consider the FH scheme we alluded to previously. If there were four FH algorithms, acting independently, would it not be possible for each FH grouping to share one time slot simultaneously? The TDM cycle would then be reduced from 210 to approximately 65 time slots. Let us examine this situation further.

It was suggested previously that four FH algorithms be used: one each for the three major elements and one for the major element to TLOC link. The TDM cycle would be as low as four slots for the major element TLOC link. One slot is needed by the TLOC to send acknowledgments and responses. Thus, the delay before transmission on this link would be no more than 4/10 of a second. Since these nodes are the most active, it is appropriate that they incur only a short delay. Now, referring to Figure 4.8 we see that the division has 75 packet radios. In order to accommodate 75 packet radios, the TDM cycle would have to be 75/10 or 7.5 seconds. The group with 50 packet radios would have a TDM cycle of 5 seconds, and the wing (air element) 85/10 or 8.5 seconds.

To cut the TDM cycle even further, we could use the concepts of spatial reuse. By relying on the capture phenomenon, spatial reuse allows packet radios from physically separated groups to use the same time slots as long as transmission power is minimized. For example, each regiment of the division might be able to share joint time slots. If the regiments were separated far enough to allow efficient use of capture then the division TDM cycle could be reduced to 7.5/3 seconds.

Let us analyze this scheme in relation to the traffic estimates developed earlier. We stated previously that the MAF, as a whole, would send at most a request once every six seconds. Divided evenly between each major element we could say that individually the division, wing, and support group send a request every 18 seconds (assuming the most active conditions). Even without spatial reuse there is an 18-7.5 or a 10.5 second buffer between the most active arrival rate expected for the division and the capabilities of the network. There is a substantial 13 second buffer for the support group and a 9.5 second buffer for the wing. It would seem that TDM, used with FH spread spectrum, can accept and process data through the busiest nodes faster than the highest expected request rate. Keep in mind that, although more analysis is required, this request rate is two and one half times greater than the busiest garrison MAF.

How many requests could this system process? Since this is a hierarchical topology where each packet requires a retransmission, an acknowledgment, a response to a received packet, and a response acknowledgment, only one packet could be received every four cycles by a senior node from one of its subordinates.[18] For example, let us assume a battalion headquarters has seven subordinates. The senior node (the battalion) is assigned only one slot in the TDM cycle. Whenever it receives a packet, it must first retransmit that 'packet' up through the hierarchy, then send back an acknowledgment, and acknowledge and pass response traffic. This could take as many as four TDM cycles or 30 seconds which means that each battalion could process one request every 30 seconds or 1200 per a 10 hour day.

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[18] A senior node is defined as the next higher to a subordinate node in the hierarchy.

Since the major element headquarters are equipped with a second packet radio to retransmit packets on a different FH frequency, two cycles per packet are needed to perform the acknowledgment and response tasks. If the average number of packets received at these nodes exceeds two per cycle, the major element node could develop an explosive queue. This means the average packet arrival rate at the wing headquarters cannot exceed one per every 17 seconds (2 X 8.5 second TDM cycle) assuming that all packets are received without error, this would allow the wing to submit a maximum of 2118 packets per day. If 50% of the packets submitted were not received correctly this would cut the number of unique packets to 1059, 1200, and 1800, for the wing, division and group, respectively for a total of 4059. These transmission rates are a little short of the estimated maximum estimated requisition rate from Table 2 (6100 per day). However, it is possible to increase the maximum network capacity for a very small overhead cost. Let us say that we assign two time slots to the major element headquarters nodes per TDM cycle, instead of just one. This would allow two packets to be transmitted during every TDM cycle which would, in effect, double capacity at the expense of adding 1/10 of a second to the TDM cycle. The topic of capacity, as it relates to hierarchical flows, will be addressed in the control section.

Another possible method for increasing the capacity of the system is to send more than one acknowledgment, or response, in one slot. Later on when the structure of an acknowledgement is explained, the possibility of sending up to seven acknowledgments and six responses in one time slot will be demonstrated.

Still another method used to increase the capacity of the TDM protocol takes advantage of the fact that request packets must begin at the start of a time slot. Once a time slot assigned to a subordinate node begins, the next higher echelon or senior node could sense the channel. If the slot was not being used, the senior could initiate the transmission of an acknowledgment or a response i.e., stealing an unused time slot. Since acknowledgments and responses are generally smaller than request packets, this is a reasonable option. This form of time slot stealing, however, should only occur between senior and subordinate hierarchical nodes. If the senior steals slots of other units not assigned to it, collisions may occur as a result of hidden terminal problems. It is assumed that the senior and all subordinates can easily hear each other. Collisions involving acknowledgments are most damaging to network performance, therefore the practice of stealing other unassigned node slots for this purpose should be avoided.

One more procedure that could be used to increase capacity is to require a terminal that has stopped transmitting to send a delete packet. The delete packet would indicate to the next higher echelon that it will not transmit again for X number of minutes. As a result, that slot could be used by the senior node for its own purposes. Additionally, it is estimated that it will take at least 30 seconds to input transactions on a keyboard. Programming this fact into the senior node packet radio would allow the senior to use, for three to four time cycles, the time slot of a node having just completed a successful transmission.

5. **Synchronization**

It is difficult to add and delete time slots or members to the TDM cycle. Any change in the TDM cycle during an operation is hazardous. All members would have to change their respective places in the TDM cycle. The total number of slots and packet radios required must be accounted for prior to the time the network initiates operations. By adding a new member we mean someone who was unaccounted for previously. This would be a rare event in a military operation since everyone should be accounted for before a maneuver. This is not to say that a unit cannot get on and off the network. As long as there is a time slice provided in the TDM cycle a node can transmit and cease transmissions at any time. In this case deletion means being dropped from the TDM cycle, not ceasing transmissions. Initiating and stopping transmissions is easy, but adding and deleting members is more difficult. Therefore, the case of a node that became inoperable (but was repaired) and now wants to begin transmitting again, is taken care of since its slot remains in the TDM cycle even while it is being repaired.

In the above paragraph we assumed that a node will stay in synchronization even if the packet radio is turned off or becomes unserviceable. The easiest way to insure this is to associate the FH algorithm with time of day or with the time the operation commenced. In this way, each packet radio would have an independent clock that would drive the FH and TDM synchronization. The clock synchronization would have to be maintained 1/10 or 1/20 second intervals. Whenever a packet radio was turned off and then turned back on again, it would know where the network was in the FH algorithm. To insure that slippage did not occur, senior nodes could transmit synchronization packets at various intervals on a predesignated frequency. The synchronization packet would provide both the proper time, in its data element, and the proper slot initiation point. Thus, even if a node became totally out of synchronization it could get back on line by listening to the special synchronization channel and waiting for a synchronization packet.

6. Throughput

As as a result of using a TDM protocol, a great deal of spectrum is not utilized and throughput in relation to available bandwidth may be poor. In fact, from our initial estimates, the division can process only one packet, transmitted in 1/10 of a second, every 15 seconds.[19] In the commercial sector this would be a highly important concern, but in a military operation it is not such an important consideration. As a matter of fact, the less the channel is used the better, since more use increases the probably of enemy detection. Of course, the means to increae capacity described in the multiple access protocol section would increase this throughput rate i.e., slot stealing and or adding extra slots, etc. Throughput is also affected by how the channel is used with FH. As stated previously, FH allows packets to be sent over, or very close to, analog voice frequencies at the same time the voice channel is being used; allowing for the possibility of more than 100% utilization of the available spectrum. Still, it is important to keep in mind that throughput does not have the same meaning in a military context as it does in a commercial application.

7. Acknowledgment Wait Time (Data Link Layer)

The wait for acknowledgment time does not have to be random when using a TDM protocol. The acknowledgment process should be fast enough to allow acknowledgment prior to the next scheduled time slot. Thus, if the TDM cycle was five seconds, and the acknowledgment had not been received within five seconds, the packet would be retransmitted the next time the node was given the opportunity to transmit. This may prove difficult, however, if the TDM cycle is short as in the case of the major element to TLOC link. A node may have to wait two or three cycles before retransmitting on this link. To insure reception, if the traffic will allow, it may be advisable to send acknowledgments more than once prior to the retransmission time.

The point here is that retransmissions do not occur on a random basis. If a collision occurs, and if both members are on different FH cycles, not only will they transmit on a different frequency the next time, but they will also transmit during a different time slot. Since the number of members in each FH/TDM cycle is different, this requires different length TDM cycles. A problem may arise if two packets of the

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[19]Two cycles (7.5 seconds each) are required for the acknowledgment and response, the retransmission being sent on a different frequency.

same FH TDM cycle collide. This problem would then have to be identified by distress packets and resolved by the network control functions.

8. Character Representation (Presentation Layer)

The character representation scheme should be minimized to use the least amount of spectrum and to increase transmission speed. Keeping the transmission time short will shorten the size of the time slot, which will reduce the TDM cycle time. A reduced TDM cycle time will have a significant effect on all the statistics developed previously. An analysis of the type of data required by the system is necessary to select the appropriate character representation scheme.

By observing the data dictionary in Figure 4.7, it can be concluded that the 26 letters and the 10 digits are utilized. However, no distinction is made between upper and lower case. Since 'sentence type' remarks are possible, the basic punctuation marks are necessary (. , ? ! ( ) : ; '). Additionally, a number of special symbols are required to save space when keying sentences (# $ % + = / BLANK, END OF DATA). This adds up to: 26 letters, 10 digits, 9 punctuation marks and 8 special symbols making a total of 53 characters. Thus, a 6 bit character representation would be adequate for this application. There also may be a need for one or two control characters to frame packets shorter than the standard 80 data character packets. But for the standard data packet there are specific formats which make it easy to distinguish between different card column characters. There may be a need for other control characters within the packet radio and the terminal equipment, but these would not require transmission. Rather, they would be for internal node processing. As a result, with a 6 bit character representation scheme there are 64 symbols possible with only 53 being used. The difference of 11 will become more valuable later on when we describe error detection methods.

9. Packet Structure

The packet itself will consist of three sections: the header, the data and the error control section. Again, we will try to minimize the data contained in each section for security and efficiency reasons.

a. Header

The header section normally contains the address, routing information and the packet number. Packet numbers are not required since most transactions sent over this network are less than 80 characters in length. The only exceptions may be remarks that cannot fit into the space provided or a paragraph type request that requires a detailed explanation. The need for a message longer than 80 characters is not highly probable. It should, in fact, be discouraged since other communication channels are allocated for paragraph type input. A network to support Marine Corps logistic communication is essentially a digital computer-to-computer channel, transmitting simple inquiries and responses. The added software complexity required to reassemble long multi-packet messages is not needed in this situation.

For those unusual instances when multi-packet messages are necessary, card columns 79 and 80 can be used to indicate the packet number. The operator at the destination can then manually assemble the message. If a unit needs to send a multi-packet message a 0,1 would be put in card column 79 and 80 of the first transmission. This would indicate to the operator that there would be more to come. This sequential procedure allows a unit to send one message in up to 99 packets for minimum cost. The last packet in a sequence would always contain a 99 to indicate end of message.

There is no reason to address the destination in the header since all routing is fixed in a predetermined direction up through the chain of command. In fact, we could get away with not even addressing the sender, since the TDM cycle would identify the sender. However, as a back up, and as a quick authentication scheme, it would be wise to place a unit identification code in the header. Since it is estimated that 210 packet radios are required by the MAF, an eight bit identification code is necessary. Thus, a maximum of 256 packet radios would be allowed on the network.

In addition to the eight bit identification code a one bit distress code is required. One routing information bit is also necessary to insure packets are passed in the proper direction (either up or down the hierarchy). Thus, the header will contain only ten bits; one distress bit, one routing bit and eight bits for the unit identification code.

b. Data

The data section of the packet will contain only the 80 characters of data per transaction. Each character will be six bits in length for a total of 480 bits. If card column 80 is not used then an 'end of data' character will be placed after the last data character. This is done to shorten the packet and to indicate that the next bit will be the first of a fixed number of error detection bits. The end of data character will be placed in the data section by pressing the enter key.[20]

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[20]A method to insure transparency of this character would be required. Bit

The number of bits in the data field could be shortened by making use of the fact that some of the data in the packet is repetitive and unnecessary. The six character unit ID could be converted to an eight bit unit identification code. Another example is the julian date. A program module could simply place the appropriate date in this field without requiring it to be transmitted from one node to another. Similarly a program module could replace the 36 bit unit ID code with an 8 bit unit identification code. These actions would be accomplished at the presentation and session layers. It would be advisable, however, to require that the user continue to input these codes since it may be difficult to adjust to such a drastic procedural change. Physically, the user would input 80 characters of data but only 70 characters and the 8 bit unit identification code, or 428 bits, would be transmitted.[21] Both the unit ID and the julian date are mandatory entries for all request packets.

c. Error Control

The last section of the packet contains the error detection bits. Error detection is extremely important in radio data communications. Radio is inherently vulnerable to many factors: weather, geography etc. Military applications normally require operations in the most hostile environments possible.

There are two distinct error control categories: One is transmission error and the other is input error. Transmission error is caused by radio propagation while input error is caused by the user. We will treat both categories separately, applying different methods to each.

To begin with, input errors could be detected prior to transmission by having the packet radio alert the user or the terminal equipment would detect the errors at the receiving end. Economically it would be better to have the packet radio check the input prior to transmission. This would save spectrum and increase security and efficiency.

In order for the packet radio to check input errors it would have to match each field with the data dictionary. For example, card column one is the first character of the document identifier field. This field has only 10 possible entries. If the input for card column one did not match one of the valid entries, an error signal would be sent to the operator. The remaining fields in the request follow a standard format which

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stuffing may suffice if a bit synchronous protocol was used.

[21] To clarify, There are now two 8 bit unit codes: one in the header that changes every hop and indicates the transmitting node and the other in the data section that identifies the original requestor.

can be checked in a similar manner. Some fields, however, are only limited by being alpha or numeric and still others have no constraints. This information is contained in the data dictionary.

The error checking described above would demand a fair degree of memory and logic from the packet radio. However, with today's processing technology this may be feasible. Additionally, to improve error checking the user could personally program some of the request fields. A field such as unit ID is standard for each packet radio and the user could program the input error check to accept only one particular unit ID.

There are a number of methods to detect, and in some cases correct, transmission errors. One correction method involves the use of a hamming code which inserts parity bits into a string of data bits. The parity bits are placed in bit numbers that are a power of 2. The parity bits are included in a sequential bit numbering scheme. For example, the bit stream 1100010 would have four extra parity bits inserted and each data bit would be checked by at least two parity bits. By a process of elimination, this cross referencing detects and corrects errors [Ref. 13: p. 97]. The hamming code can be used on any length message. For a message of less than 503 bits 9 parity bits are necessary to perform error correction. One drawback to this method, however, is that only single bit errors can be corrected. If more than one bit is transmitted incorrectly, then the correction process will not work. This may be an important constraint since errors in radio transmission may, for the most part, occur in groups of more than one bit.

The longer the message, the greater the chance of multiple errors. But if the message is short then the overhead required for the hamming code is proportionally higher. In the above example we needed four overhead parity bits to check seven data bits. This additional overhead also increases the probablity of a multiple error, since four more bits are being transmitted for every seven data bits.

Another method for checking errors is to insure that each 6 bit string represents valid characters. In our character representation scheme, 53 out of 64 strings are used which means 11 string sequences are not valid. If one of these invalid sequences is received, then we can identify these incorrect characters.

An error detection check that will detect almost any error is the cyclic redundancy check (CRC). This works by dividing the transmitted bit stream, which can be several thousand bits long, by a certain number. The remainder is taken to 16 bits and then placed at the end of the packet. When received, the data stream is again divided by the same number and the 16 bit remainder is matched against the 16 bits at the end of the packet. Usually if the two numbers match there has been no transmission error. There is a remote chance, however, that the remainders will still match even though there has been a transmission error, but this is a rare probability [Ref. 4: p. 128].

For the price of 16 bits in overhead, it is recommended that a CRC be utilized. Sixteen bits will be reserved at the end of each transmission to perform a CRC check. This will give us a packet of 10+428+16=454 bits. It is also recommended that remarks which are only contained in specific positions not be included in the CRC check. Errors in these fields may be better detected and/or corrected by operators.

With 454 bits of data, what is the most economical use of the hamming code method? The 454 bits could be sliced into segments of 120,120,120, and 94, each requiring seven parity bits. This provides the capability to make up to four corrections, as long as each error falls into the right segment. A more precise use of hamming parity bits would cause the packet and TDM cycle to be too long. However, it is presumed that most radio transmission errors will occur in groups of more than one bit. If this is true, the added overhead of using parity bits may not be worth the correction ability offered by a hamming code. Perhaps, a hamming code should be used only on specific and crucial fields. A more feasible allocation of the hamming code technique follows.

To reduce the use of parity bits we could allow four parity bits to check the header. Seven parity bits could be used to check the stock number field (13 digits). Then we could check the 16 bit CRC with 5 parity bits. What we have now is 16 extra parity bits for a maximum packet length of 470 (Figure 4.9). If we assume 9600 baud, which is the rate used by ALOHANET [Ref. 5: p. 203], our packet transmission time is: 470/9600, which equals about 49 milliseconds, a fraction under 1/20 of a second.[22] As a result, our system capacity has doubled because the TDM cycle has been reduced by one half.[23]

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[22]If bit stuffing is used to implement transparency, a few extra bits may be required but for this analysis a 1/20 second transmission time will suffice.

[23]More research may indicate that hamming parity is not feasible at all for radio transmissions but the above scheme provides us with a maximum packet size.

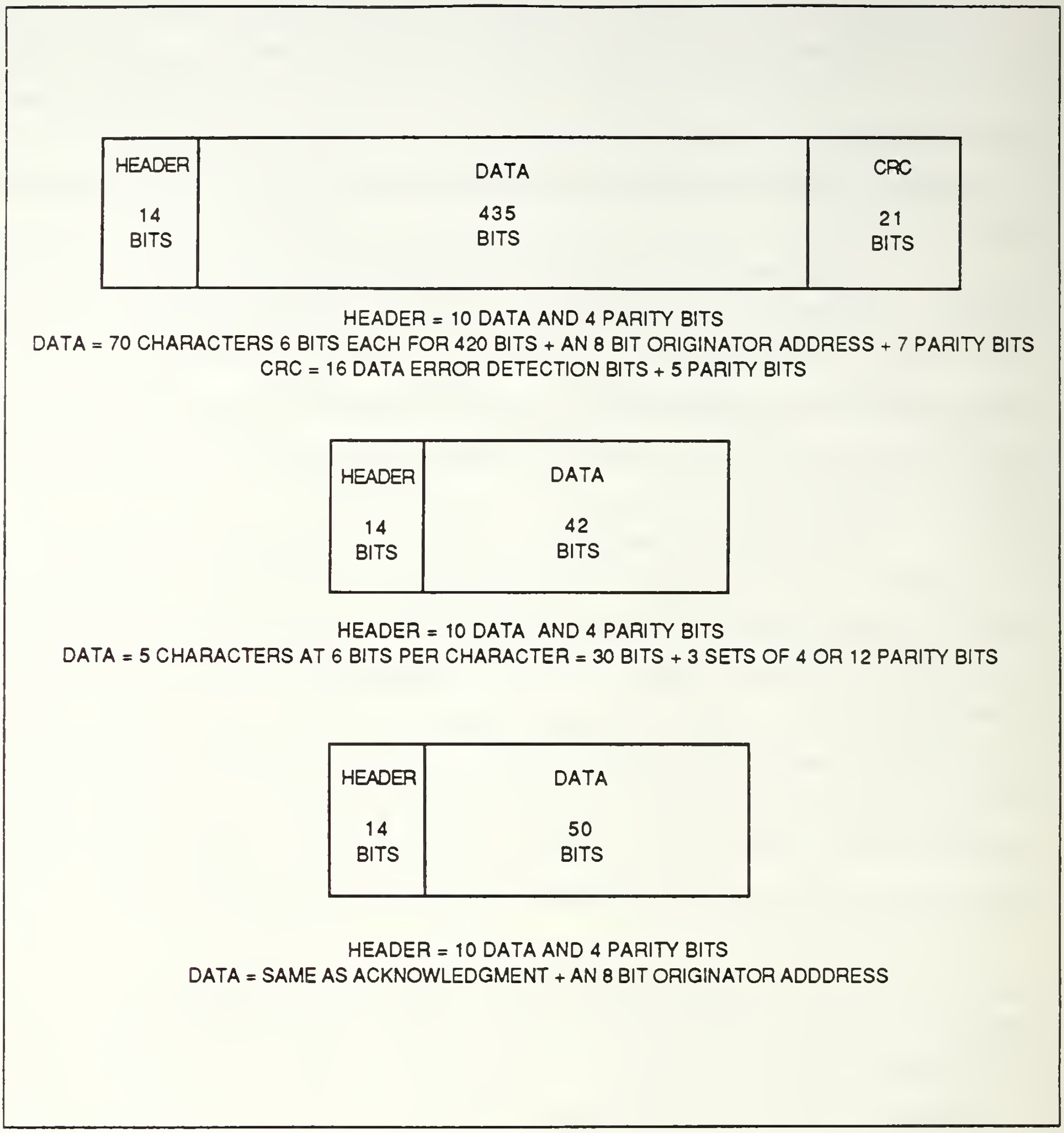

Figure 4.9 Packet Structures.

10. Acknowledgment Packet Structure

Acknowledgment packets will be structured with only a header and a data section. The header will contain the destination address as opposed to a request packet that needs the sender's address. Previously, the receiver was always predefined, but now the situation has been reversed so that the sender is known and it is the receiver's address that is required. To keep the size of the header standard for every transaction the distress bit will always be set to zero since no acknowledgment to acknowledgment is planned. Acknowledgments are assumed to be received correctly; if not, the packet will be retransmitted. Therefore the header of an acknowledgment will consist of ten bits.

The actual data will consist of the last four characters of the document number (serial #) and an acknowledgment indicator which will be either an N or an A. A is a positive acknowledgment; N is a negative acknowledgment. Thus, the data section will consist of 30 bits. There is no need for a CRC code because if the acknowledgment is incorrect there is no easy way to ask for a retransmission.

When a packet is transmitted, a copy of that packet is saved in a pending acknowledgment file. When an acknowledgment is received its data section document number is compared against the entries in the pending file to find a match with card columns 15-18.[24] When the match is found, the acknowledgment indicator is checked to determine if the acknowledgment is positive or negative. If positive, the packet is erased from the pending file and stored in a history file. If negative, the packet is automatically retransmitted.

Since there is no CRC check in the acknowledgment we will make the most use of the hamming code method. Since four bits are always used to check the header, and considering that as many as eleven data bits can be checked with four parity bits then the 30 data bits can be divided into segments of 10 data bits, each of which are checked by four parity bits. This will produce, as shown in Figure 4.9, a packet of 56 bits.

Since a time slice is long enough to transmit a request packet of 470 bits we could transmit as many as eight acknowledgments in one time slice. However, a transparent "beginning of packet" character would be required at the beginning and in between acknowledgments. This character could be as long as 11 bits[25] and still seven acknowledgments could fit in each time slot. Also, since the acknowledgment is so small, it could be sent after a shorter than usual request packet or response. The small size of the acknowledgment offers many options. Ideally, acknowledgments should be transmitted at a higher power since they are more critical to network performance. A

[24] Two packets with the same serial number could not be placed in the pending file at the same time. One would have to delay its transmission until the first was acknowledged.

[25] This character could also provide the required radio synchronization for unsynchronized packets.

higher transmission power will allow capture of the channel, by acknowledgment packets, over any request packet.

11. Response Packet Structure

Responses are required for each request but most responses contain only a simple status code i.e., filled, passed or cancelled. Both filled and passed inventory responses transmit only a status but cancelled responses may require an explanation. Most service type requests will also require some explanation or coordinating instructions. The responses requiring explanations will be a full 80 characters long. It is estimated that 50% of the inventory requests would be fills, which is about 35% of the total request rate. About 75% of the NIS (passed status) requests will not require an explanation and represent approximately 26% of the total request rate. In addition, it is estimated that about 20% of the remaining requests will not require explanation; this being about 13% of the total request rate. Thus, 74% (35+26+13) of the responses can be sent without explanation. These responses can be structured like acknowledgments but instead of an acknowledgment indicator, the F/P/C code will be sent. However, an eight bit address must be included in the data section to identify the originator (See Figure 4.9). Thus, six of these responses could be transmitted in one time slot. It still would be advisable to display the response in a full 80 card column format in accordance with the data dictionary to make the information more readable. However, what is actually transmitted would be only the few essential characters.

12. Physical Layer

Keeping in mind the constraints of hamming coding (the ability to correct only one error), we should choose a modulation technique that does not send two or more bits per baud. If we did transmit in this manner most of our errors would be in groups and the effectiveness of the hamming code would be reduced further. A single bit modulation, although slower, is much more reliable. A simple "phase shift keying" technique, for instance, would be more than sufficient for this application. This type of modulation is easy to detect and is less affected by noise than AM and FM modulation.

Frequencies can vary from 300 MHz to 30 GHz for practical packet radio usage (VHF-SHF) [Ref. 6: p. 1471]. This means line of sight communications is required. The higher the frequency, the less effect multipath has on transmissions but the more the need for directional line of sight links. An example would be in the jungle where high frequencies from 1 - 30 GHz would prove ineffective since vegetation would prevent line of sight communication. Rain will also affect higher frequencies. On the other hand, higher frequencies are much harder for the enemy to detect since they are more directional.

As a general rule, if the geography and conditions will allow, higher frequencies are preferred but enough flexibility has to be built into the radio itself to allow the reception and transmission of a variety of frequencies. The actual situation should dictate the frequency used, not the hardware. Unfortunately, hardware capable of modulating over VHF to SHF ranges simultaneously may be prohibitively expensive and bulky.

F. NETWORK CONTROL (NETWORK LAYER)

The last section of this chapter will examine the network station. The network station is the node that performs the central control functions of a packet radio network. The station also acts as a gateway to other networks. Previously we have referred to the central support activity or TLOC. This is the node at the top of the hierarchy to which all requests flow if they cannot be satisfied at a lower level. In view of this the TLOC is the logical place to position the packet radio network station.

Control over the network can be either centralized, in which case the station performs most of the network control functions, or decentralized, where the individual nodes control the network. Decentralized control is more robust in the sense that network operations will not cease if one particular node is destroyed. However, centralized control is more efficient since decisions can be made with consideration for the network as a whole. There are a number of tradeoffs associated with the allocation of control functions. In this packet radio network we will examine the various control functions, determine if there is a need for control, and where this control should be placed.

1. Flow Control

Flow control insures that network equipment does not develop explosive queues. Flow control, for our network, is actually performed by the users. The keying of data takes a relatively long time, taking into consideration that most data will be entered by nontypists on a small mobile keyboard. There are only so many requests one user can enter in a specific period of time.

Let us analyze our situation again with the largest type of landing force, the MAF. There are a total of 210 packet radios; 50 in the group, 75 in the division and 85 in the wing. Let us assume that it takes at least 30 seconds to key a request and transmit a packet.

The structure of the wing element was presented in Figure 4.8 previously. What will happen if every node begins transmitting continually i.e., every 30 seconds? Let us start at the bottom and work up. If each of the five LAAM Bn. batteries transmit a packet every 30 second, the battalion node will receive one packet every six seconds. The TDM cycle time is four seconds long. Keeping in mind that response and acknowledgment traffic can be sent in any stolen time slot, if a packet is received, at the most every six seconds, and the LAAM Bn. node can retransmit every four seconds, no substantial queue will develop. In fact, as long as no more than seven units are submitting packets every 30 seconds (one received per cycle), to any one node, the network will avoid congestion. Neither of the flying groups nor the HQ squadron have any more than six subordinate units. The control group has six squadrons with the 5 LAAM batteries subordinate for a total of 11, while there are 8 subordinates attached to the support group.[26] Both the control group and the support group can steal slots from their subordinates that input at the slow keyed rate.[27] As a result, acknowledgment and response traffic can be ignored for this analysis. However, in both cases, an extra slot is needed to prevent congestion. With two slots per cycle assigned to a node, it can then support up to 14 subordinates. The wing headquarters has 84 subordinate units, but the wing is a headquarters node which retransmits packets on a separate radio and only needs its slot to transmit acknowledgments and pass responses. Acknowledgments may be sent seven at a time, or 49 every 30 seconds. Also, slots can be stolen using channel sensing. Still, it may be advisable to add two or three time slots to the wing headquarters for insurance purposes.

The same type of analysis can be done for the group. Since the TDM cycle time for the group is 2.5 seconds, as long as one unit has no more than 12 subordinate units there should be no congestion. As Figure 4.8 indicates, no unit, other than the group headquarters, has more than 12 subordinates. Since the group headquarters,

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[26]The battalion or squadron nodes are not counted since requests from the headquarters are submitted by the headquarters company/squadron node.

[27]Nodes that key input use only one slot every 30 seconds while others (senior nodes) could use their slot every TDM cycle since they process the input from many users.

like the wing headquarters, retransmits packets on another radio, no delay should result in the group. However, an additional slot may be added to the group headquarters in order to process efficiently any unexpectedly high response traffic.

The division has a TMD cycle time of 3.75 seconds which means a senior node can have no more than eight subordinates. Each infantry battalion has six subordinates, so no problem should develop at this level. There are 19 subordinate units in each infantry regiment, however, requiring each regimental node to have two extra slots to keep pace. Figure 4.10 graphically demonstrates this procedure. This would mean that the total number of slots assigned to the TDM cycle would now be 81 versus 75. This would create a cycle time of 4.05 seconds which would mean that only seven subordinates per slot could be assigned to a node. The infantry regiments would still be able to support 19 subordinates since with 3 time slots they could support 21 subordinates. The most congested node is the division headquarters, with 74 subordinate nodes arranged in a narrow hierarchy. The division headquarters, like the wing, would require an additional two or three slots also.

The TDM cycle for the TLOC link is 4/20 or .2 seconds and it supports 209 customers transmitting packets every 30 seconds which is one packet every 30/209 or approximately 0.15 seconds. Packets are received only 0.15 seconds and must be acknowledged (and responded to) within a time slot that occurs every .2 seconds. If another slot was assigned to the TLOC, congestion could be avoided. Again, all acknowledgments and most responses are small enough so that many of them can be sent in one time slot. In 30 seconds the TLOC could acknowledge (30/.2) X 7 = 1050 packets. But, will the terminal equipment be able to handle one transaction every 0.15 seconds. If the programs were kept in memory, interrupt and I/O time would be reduced. This may leave 1/10 of a second for instruction execution. At an execution rate of 900 nsec., the programs would be limited to 110,000 micro instructions

The first section of this chapter indicated that processing time could be increased by connecting additional machines to the TLOC node. If three computers were used then the time allowed for one transaction would be increased to 3/10 of a second, tripling the possible number of instructions.

Printing equipment may pose a problem, however. Issues would require location slips and NIS requests would require printing or display for review, but less than one line of printing would be required in each case. Issues would require a 13 digit stock number, a 10 character location and a 14 character document number for a

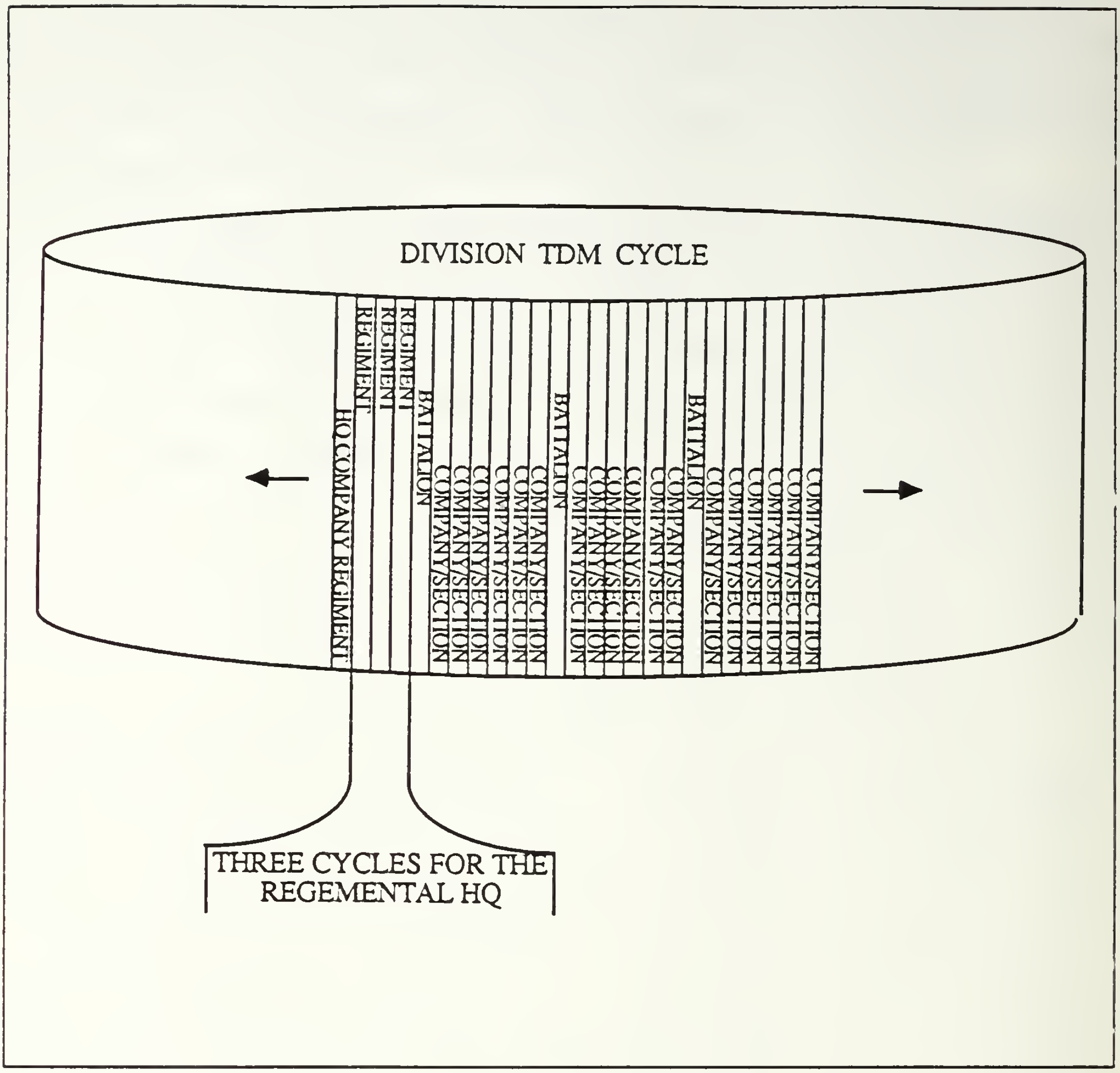

Figure 4.10 One Regiment of the Division TDM Cycle.

total of 37 characters. NIS requests and review type transactions would require the full 80 card column transaction, but could be displayed on any number of terminals. All parts issues, which may amount to 35% of the transactions, would be spooled to a printer in the warehouse. At an issue transaction rate of one every .43 seconds (.15/.35 = .43), the printer must be able to print about 86 characters per second. It may be necessary, therefore, to maintain multiple printers in the warehouse. Locations could be sorted based on a review of the most significant location character and sent to the printer closest to that location, thereby improving retrieval time.

The review requests, in this case, would be sent to the specific support manager. In fact, what is envisioned is a TLOC where each major support function (maintenance, engineer, etc.) has its own terminal. As requests requiring review arrive, they would be displayed instantaneously and the support function manager would take the appropriate action. To keep pace, Supply may need four or five displays and a number of printers, but, since this terminal equipment is already available, no extra expense would be incurred. If needed, both the equipment and the manpower are available to handle this extraordinary request rate.

Flow control for this network is basically maintained by the 30 second input constraint on the user. The network processing nodes, with some minor adjustments, can accept input as fast as the user can provide it. As a result, there is a great deal of leeway available in relation to the problem of congestion.

2. Network Integrity

Another control function is the assurance of network integrity. In other words, are all the routes via the hierarchy unobstructed so that each of the nodes can communicate with other nodes when the need arises?

When a link in one of the routes fails, a number of distress packets will be generated which may cause flooding of the network. Thus, once a distress packet is received, the station must immediately determine why the distress packet was necessary by requesting a communications check on the communication link. The communications check packet is sent to the requesting unit which will inform every intermediate unit that there is a communications link problem. Each member, in turn, will manually check its own communication link. Once the bad link is identified, a response is sent back to the station. The operator of the station will reassign the affected subordinate nodes. The unit responsible for the failed communications link will solve the problem by adjusting position or power, or using an extra repeater.

The ability to quickly reassign nodes in the logistic hierarchy must be a simple and well defined process. Even though this occurs infrequently it might be required in the early phases of a landing because units move ashore in stages. As a result, units must be quickly reassigned to different seniors nodes to maintain logistic channels. Use of address add and subtract packets facilitates reassignment (see Figure 4.7). As a matter of routine, this capability should be available not only at the station but at all senior nodes. This would allow a field commander to deploy units in any manner he deemed appropriate without concern for logistic channels. Of course, if such action is taken, it would be advisable to inform the station. Senior nodes would send address add packets containing up to 50 addresses in order to reassign units to another senior subordinate. An example of this is when a regiment sends an address add packet to add a company from one battalion to another battalion. These packets would automatically update the receiving packet radio program that checks headers to identify those packets it must process.

3. Other Control Functions

There are a number of other control functions but most are, by nature, part of the network framework. Throughput control is fixed by the TDM protocol while security is insured by the FH algorithm. Error control is conducted by CRC checks and hamming coding. Therefore, the control functions of the network are for the most part built into the network structure. The station may have to react to an increase in traffic by adding more processors or printers but the only additional functions performed by the station are redistribution and interfacing. Otherwise, the station acts very much like any another node. The data flow diagram and structured chart drawn for the nodes could be applied to the station with a few modifications such as those relating to redistribution and network interfacing.

a. Redistribution

The redistribution function processes NIS supply requests that have a potential for redistribution. Each NIS request Stock number is checked against a file, containing the allowances and on-hand values, for all the issue points in the battle zone.[28] If a match is found, an X is placed in card column four to indicate that the item is a redistribution candidate. Upon review, each redistribution candidate is first validated for the correct stock number by a supply clerk. If valid, a special broadcast request is used to inform all the other issue points on the battlefield. A copy is then placed in a pending redistribution file. Each issue point checks to see if the item is available and either a positive or negative response is then sent back to the station. If a positive response is received, the response is displayed and a redistribution direction packet is transmitted. The operator forms and transmits a redistribution direction packet by placing a D in card column two of the response which keys a process that performs this action.

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[28]This file would require batch updating every three or four days.

b. Interface Function

If a redistribution candidate was not available at any of the issue points, the demand must be reformatted into a SASSY[29] standard supply document. This is accomplished by sending the request to READ F/P/C code with a P in card column four at the station. This document must then be placed into the pending SASSY file. Prior to the time a SASSY update is run, this file must be dumped to a disk and input into the SASSY cycle. SASSY will reformat the request for submission into AUTODIN. If a DFASC is present the disk could be sent by courier, otherwise the information on the disk must be transmitted via the supporting message center to the closest garrison SMU.[30] This action would enable the station to perform a gateway function by allowing certain transactions to be accepted by other networks and systems.

There are two advantages to this procedure: One, it allows updated SASSY files and records to be maintained. Two, it takes advantage of SASSY's ability to access the numerous large files that are required to reformat demands for AUTODIN input. For instance, each stock number must be identified with a DOD source of supply. Thus, a file containing every military stock number must be accessed.

G. NETWORK HARDWARE

There are three types of packet radios required by this network which include "stand alone" packet radios, "simple repeaters" and "attached repeaters". For our purposes we will define "stand alone" packet radios as those that do not require terminal equipment to accept keyed and/or display data. These particular packet radios contain a built-in keyboard, a display and a power pack which permits operation anywhere within radio range. The "simple repeaters" are packet radios that do not have a built-in keyboard or display and do not interface with terminal equipment. They simply pass packets. The "attached repeaters" do interface with terminal equipment but do not have a keyboard or display.

In our network, the "stand alone" packet radios would be owned by the primitive level (company/section) nodes. All other nodes would maintain "attached repeaters". "Simple repeaters" would be maintained by the major element headquarters and would be used whenever a connectivity problem arose. Although flying squadrons in the wing

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[29]SASSY is the Marine Corps standard automated supply system.

[30]The SMU is the SASSY Management Unit that is the issue point's source of supply and gaters SASSY input and distributes output.

are at the primitive or packet initiation level, they already have their own IBM Series 1 and would not require a "stand alone" packet radio.

A packet radio is made up of two parts: a digital section and a radio section. The radio section is a common radio not unlike any other radio used for voice communication that transmits and receives analog radio waves. It does, however, accomplish a digital-to-analog conversion, taking computer binary signals and translating them into an analog form through modulation. [Ref. 3: p. 2]

1. Radio Section

Reliability is of particular importance in packet radio networks. Voice communication can tolerate a degree of disturbance and interference, but computer transmissions cannot. One bit of data transmitted incorrectly could have disastrous consequences. As a result, packet radios must provide reliable transmissions. The use of matched filtering and correlation techniques to combat multipath is a desired method for reducing transmission errors. The choice of simple and reliable modulation techniques would also be prudent. Omnidirectional antennas to facilitate mobile operations are usually required.

2. Digital Section

The digital section of the packet radio performs all of the required processing to implement the network protocol. Synchronization to 1/20 of a section is necessary. Also, sufficient memory is required to maintain the programmable functions i.e., input error checking and communication programs to interface with an attached device.

Preamble detection is an important option that allows authentication and identification. Thus, each packet radio within range need only read the first nine data bits to determine if it should accept the rest of the packet.

A certain degree of buffering is needed for the pending file . This memory requirement is small for "stand alone" packet radios considering the fact that packets are sent once every 30 seconds. "Attached repeaters" may require more buffer storage since they may be transmitting many times during a TDM cycle. Storage is also needed for a pending response file which must maintain 20-30 documents, but it is necessary only for the "stand alone" packet radios.

In order to accomplish hand carried packet radio operations, a built-in key board and display are necessary. This is a difficult feat due to the size constraints on the keyboard. However, the actual keys should not be too small as to adversly affect the error rate. Calculator type spacing would not be recommended because this key size is susceptible to errors Technological constraints also limit the size of displayed characters [Ref. 3: p. 111]. A possible compromise is drawn to scale in Figure 4.11.

Another important characteristic of the packet radio is its power source. Since mobility is required for "stand alone" and "simple repeaters" battery power is necessary. "Attached repeaters" can rely on a generator for power using the same generator that now powers the IBM Series 1. Battery power has always been a rare and valuable commodity in the field requiring packet radio architecture to be power conservative. One prudent option is to reduce power during listening times and to shut down the radio at other predetermined times. The ability to receive power from both a generator and a battery so as to make use of other available sources of energy is desired.

Appendices B and C contains a list of network hardware specifications as well as a model describing the network layers a packet travels when being sent through the network.

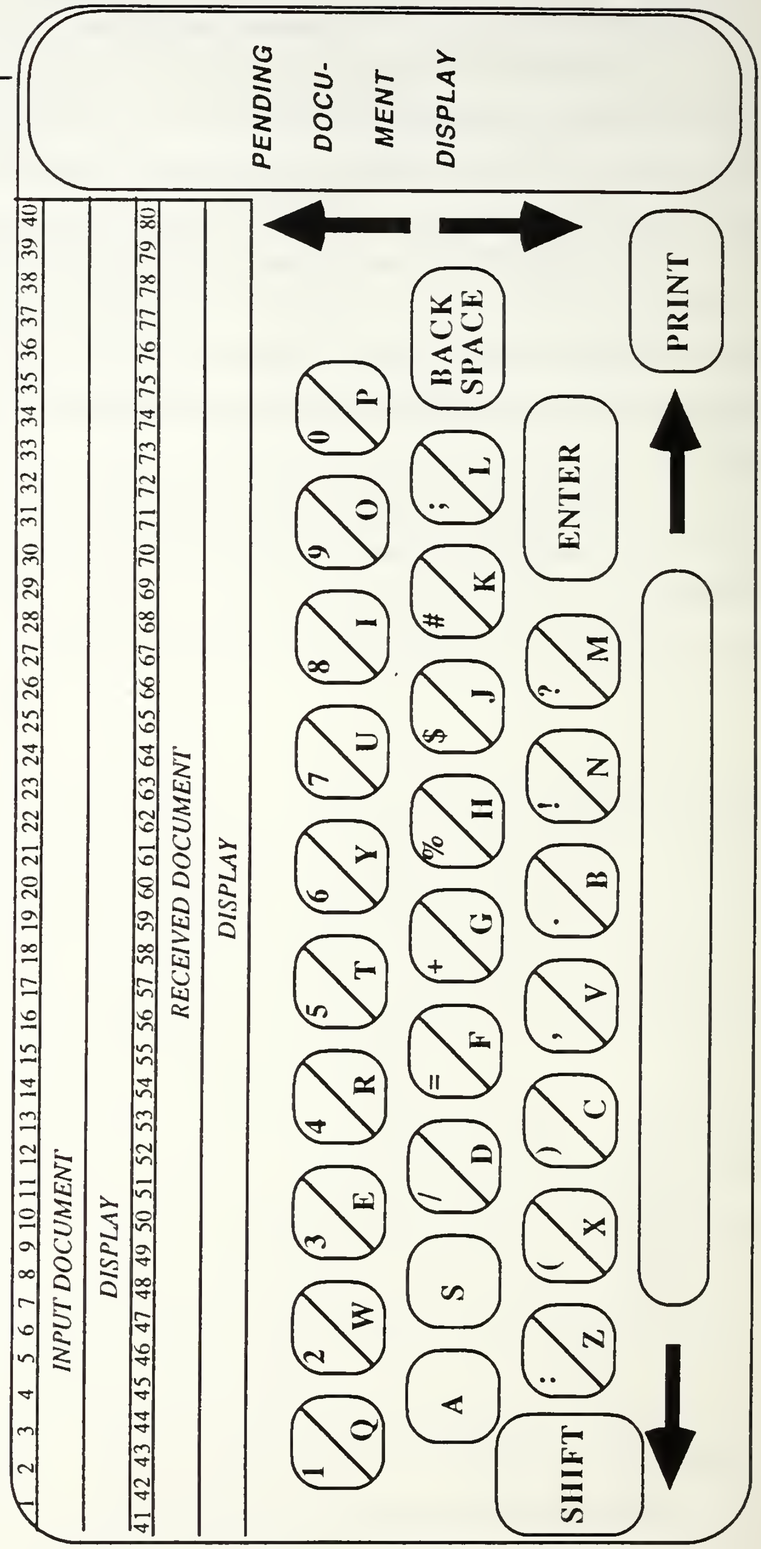

Figure 4.11 Stand Alone Packet Radio Model.

V. CONCLUSION

In conclusion we have designed a prototype network that appears to solve the problems that were originally identified by the user. The following is a synopsis of the user problems and the solutions provided by the packet radio network.

A. PROBLEMS AND SOLUTIONS

1. Communication

Communication of logistic requests are now electronic versus the standard courier. Access to any support agency on the battlefield or aboard ship by a company level command can now be accomplished in seconds as opposed to days. This access can be obtained with little, if any, affect on command and control channels.

2. Transportation

The demand for transportation is reduced because we can position support closer to the customer in a distributed manner without the usual problems associated with redistribution. Supplies can also remain aboard ship longer since customers can now easily communicate logistic requests to support functions afloat. Thus, transportation is not required to shuttle the whole supply issue point ashore in the early stages when the demand for transportation is greatest. Only those items requested need to be sent ashore.

3. Procedures

The procedure problem is not as acute since requests can be rapidly relayed from one level of command to another. Therefore, procedural delay is not substantially increased and the higher levels of command are kept informed of even the simplest supply requests. As such, S4[31] logistic officers can now become active in the support function during an operation instead of acting as bureaucratic go-betweens.

4. Node Processing

Much of the node processing is done automatically. The only time an individual gets involved in the process is when the warehouseman receives a location slip or the demand cannot be satisfied by on hand stocks. The fact that the operator is

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[31] The S4 officer is the logistic officer for units down to the battalion level.

involved only when a judgement is required, and that automatic decisions are mechanized, is an appropriate approach to data management. As a result, processes that used to take minutes now take seconds.

5. Number of Steps Involved

There are fewer steps involved and most of them are performed faster. Previously all supply part requests were researched prior to a stock check, which was a time consuming task. Now, prior to any research, stock checks are done automatically. As a result, correct requests are processed immediately while only those that are not available or are incorrect are researched.

B. ADVANTAGES

1. Capacity

We now have the outline of a logistic support network that can process ideally 205,200 requests in a 10 hour day (every primitive node[32] transmitting one packet every 30 seconds without error); about 33.6 times faster than the estimated maximum request rate of 6100 per day. This provides plenty of leeway for incorrect estimates or unforeseen problems that may occur.

2. Expansion

With adjustments to the application layer there is abundant room for expansion. Other systems that may take advantage of this network are: personnel reporting, maintenance status reporting and fire coordination.

3. Speed

Speed and asset visibility are the key advantages to this network. The original problem was that units were essentially cut off from any substantial logistic support. Now they can easily request support, by just keying a few characters onto a packet radio. No couriers or courier transportation is required to process a request. The items still have to be picked up, but the support function can now meet the customer halfway or possibly even establish a delivery service; the source being placed close to the customer.

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[32]There are 171 primitive nodes.

C. DISADVANTAGES

1. Radio

As with any radio network, it is less reliable than hardwire communications. Anyone who has spent time in the field knows that with a military unit, ground communication by radio is at best a probabilistic event. The major weakness, therefore, is the fact that data is transmitted over radio waves in a hostile environment. In view of this a great deal of emphasis must be placed on purchasing quality radio equipment.

To increase reliability we could reduce the baud rate from 9600 to 4800. While this would decrease the cost of the radio; it would double the TDM cycle time. We could probably cope with this when supporting only logistic requests, but room for expansion to meet future applications would be reduced.

2. Frequency Utilization and Throughput

The network will not use spectrum efficiently unless frequency hopping shares channels with other systems. Multiple FH algorithms will improve use but because of the hierarchical nature of the network only a limited number of packets can be processed through the system. Many slots will not be used. Even if every node transmitted a packet every 30 seconds constantly for a 10 hour day and every packet was received without error only 205,200 packets could be processed. In a 10 hour day there are 720,000 time slots. So the upper limit of spectrum throughput is 28.5%.

3. Delay

TDM with 210 nodes at 1/20 second transmission time develops a delay factor. Even dividing up the network into four FH groups does not improve the delay by much in network terms. The key is that the user, transmitting at the most one packet every 30 seconds, is not affected by the delay.

4. User Constraints

This network is designed to process 80 card column input. It will accept paragraph type data but this involves a cumbersome process. A packet radio network is designed to link computers and is not intended to be used as a telegraph.

There is also a constraint on the flow of requisitions. No horizontal communication is allowed because there is no perceived need to send logistic requests to a neighbor.

5. **Cost**

The hardware is the biggest cost factor. It has not been possible to obtain accurate cost figures since a packet radio is a special purpose item; however, hardware costs are generally decreasing as technology improves. Cost may or may not be a factor. The goal is to purchase a low cost but highly reliable packet radio.

6. **Security**

The development of a FH algorithm keyed to time of day has not been attempted in this thesis, however, this is conceivable and has been done in the past to support other communication systems.

D. SUMMARY

It appears that a packet radio network will solve the problem of logistic communication on the battlefield. Node processing is kept simple while the network speed provides an invaluable service to the customer. The network is flexible because only crucial fields are automatically error checked and it is reliable since control functions are not dependent on the network station. Assets can be visible in real time and can be accessed in seconds from anywhere within radio range. As a result, equipment can be maintained at a higher level of readiness, not just in the short run, but over an extended period of time.

The tangible benefit of this packet radio network is the fact that communicating the bulk of logistic demands is made possible while deployed even when the support function is aboard ship and the time required for logistic support is reduced from days to seconds. The need to communicate all battlefield logistic requests in seconds *must* justify the cost of such a packet radio network. In this thesis we have provided a prototype design, explained specific capabilities, and examined network characteristics. It is hoped that the possibilities identified herein will inspire more detailed technical research so that the described benefits may be realized.

APPENDIX A
LIST OF ACRONYMS

ALOHANET - One of the original Packet radio networks established in Hawaii.

ARPANET - One of the first networks developed using packet switching.

AUTODIN - The military Data communication system.

CSSIN - A system being developed by the Marine Corps to organize and account for assest during an amphibious landing.

DET - A detachment or unit assigned to various other units.

DMGS - A system developed to allow data communication from a deployed site to the closest AUTODIN switch.

DOD - Department of Defense

FH - Frequency Hopping

FSSG - The Marine Corp Support Element (Force Service Support Group).

MAB - Marine Amphibious Brigade.

MAF - Marine Amphibious Force the largest type landing force.

MAU - Marine Amphibious Unit the smallest landing force.

MDSS - A system being developed by the Marine Corps that attempts to provide the landing force commander with asset visibility.

MPS - Marine part of the Rapid deployment force.

NIS - Not in stock.

NSN - National stock number - used to identify and warehouse supply items.

PN - Pseudo noise modulation.

RJE - Remote job entry.

SASSY - The Marine Corps automated supply system.

SMU - SASSY management Unit the unit in the FSSG that is the source of supply for issue points and is the section the inputs and distributes SASSY output.

TLOC - The tactical logistic operation center which receives all customer requests and directs support action.

WRS - The war reserve system which stocks assest for use only during war.

APPENDIX B
MODEL

1. INTRODUCTION

In this section we will walk through how a packet is formed and how it proceeds through the system.

2. APPLICATION LAYER

When a logistic need is identified the user turns on the packet radio, looks up the appropriate format in the data dictionary and keys the request. Once the enter key is pressed the packet goes to the next step.

3. PRESENTATION LAYER

At this point the request is converted to a 6 bit code and input error detection is accomplished.

4. SESSION LAYER

The session is predefined by the TDM protocol and routing is predetermined. The unit ID is replaced with an eight bit unit identification code and the julian data is stripped from the data.

5. TRANSPORT LAYER

The packet is formed. The address of the sender is placed in the header, the request is placed in the data section. A copy of the data section of the packet is placed into the pending acknowledgment file. A program to count the number of retransmissions and set the distress bit if necessary is run.

6. NETWORK LAYER

There is no end to end protocol except the response that is generated by the application layer. The routing bit is added to the header.

7. DATA LINK LAYER.

The CRC and hamming parity bits are generated. The packet now waits for its assigned time slot.

8. PHYSICAL LAYER

The packet is transmitted by converting the bits into radio waves. The destination converts the packet to the 6 bit code being used.

9. DATA LINK LAYER

The destination reads the preamble and performs hamming correction.

10. NETWORK LAYER

The destination determines whether to accept the packet or ignore it.

11. DATA LINK LAYER

If the destination accepts the packet the whole packet is read and error correction and detection are performed.

12. NETWORK LAYER

The destination determines whether to process the packet or pass it automatically to the next level of support in which case the whole process starts again at the transport layer.

13. TRANSPORT LAYER

If the packet was to be processed then and error check bits and address would be stripped off the packet. The packet radio would send a request for interrupt to the attached processor. Otherwise, a new address would be placed in the header. In either case an acknowledgment packet would be structured and sent in the same way as the data packet was sent.

14. SESSION LAYER

The attached processor would perform an interrupt if necessary. The eight bit unit identification would be converted to a standard 6 character unit ID code. The appropriate julian date would also be inserted.

15. PRESENTATION LAYER

The data in the packet would be converted to the proper code from the 6 bit network code.

16. APPLICATION LAYER

The request would be processed in accordance with the structured chart.

APPENDIX C
SPECIFICATIONS FOR NETWORK HARDWARE

1. FOR STAND ALONE PACKET RADIO

1. Be small enough to be hand carried not necessarily hand held.
2. Be battery powered with the option of being powered by a generator.
3. Be capable of hopping frequencies every 1/20 of a second.
4. Have enough precision to maintain 1/20 second synchronization.
5. Be phase keyed modulation compatible.
6. Be able to interpret signals at a rate up to 9600 baud.
7. Have 26 data keys, a shift key, an enter key and 2 cursor keys, forward and backward to edit messages prior to transmission.
8. Have a 160 character display: 80 for the input document and 80 for received documents. Also a 4 digit wide display to view all pending documents 10 at a time is necessary.
9. Use an omnidirectional antenna.
10. Be able to perform matched filtering and correlation.
11. Perform modulation that sends one bit per signal.
12. Have a small buffer to contain two or three packets.
13. Have a 64 K memory.

    To maintain a history file.

    To store and implement a FH algorithm.

    To maintain a pending response file.

    To store a program to convert data to 6 bit network code.

    To store a program to obtain the 16 bit CRC check.

    To store a program to implement an acknowledgment scheme
14. Be able to connect to a printer to print history file.
15. Ability to display any pending acknowledgment.
16. Do preamble detection. Listen to all traffic but process only that which applies.
17. Cost per unit less than $3,000.

18. Maintenance modularized to permit easy replacement of failed sections without a lot of analysis.
19. Mean time between failure less than 600 hours.
20. Be ruggedized.

2. FOR A SIMPLE REPEATER

A simple repeater would have the same specifications as the stand alone packet radio except for specifications 7,8,15,17 and 13. Also, the size constraint would be less stringent. But the buffer size requires storage for up to 25 packets. Also the cost constraint would be reduced to $2,000.

3. FOR AN ATTACHED REPEATER

The specifications for this type of repeater would be the same as those for the simple repeater. The only additional function is that it should have the capability to be programmed by the user to automatically pass certain types of packets but at the same time send a copy of that packet to the terminal equipment for record purposes. Also, some of the memory and programming functions could be shared with the terminal equipment. Power also should be provided primarily by the terminal.

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